

J
ET

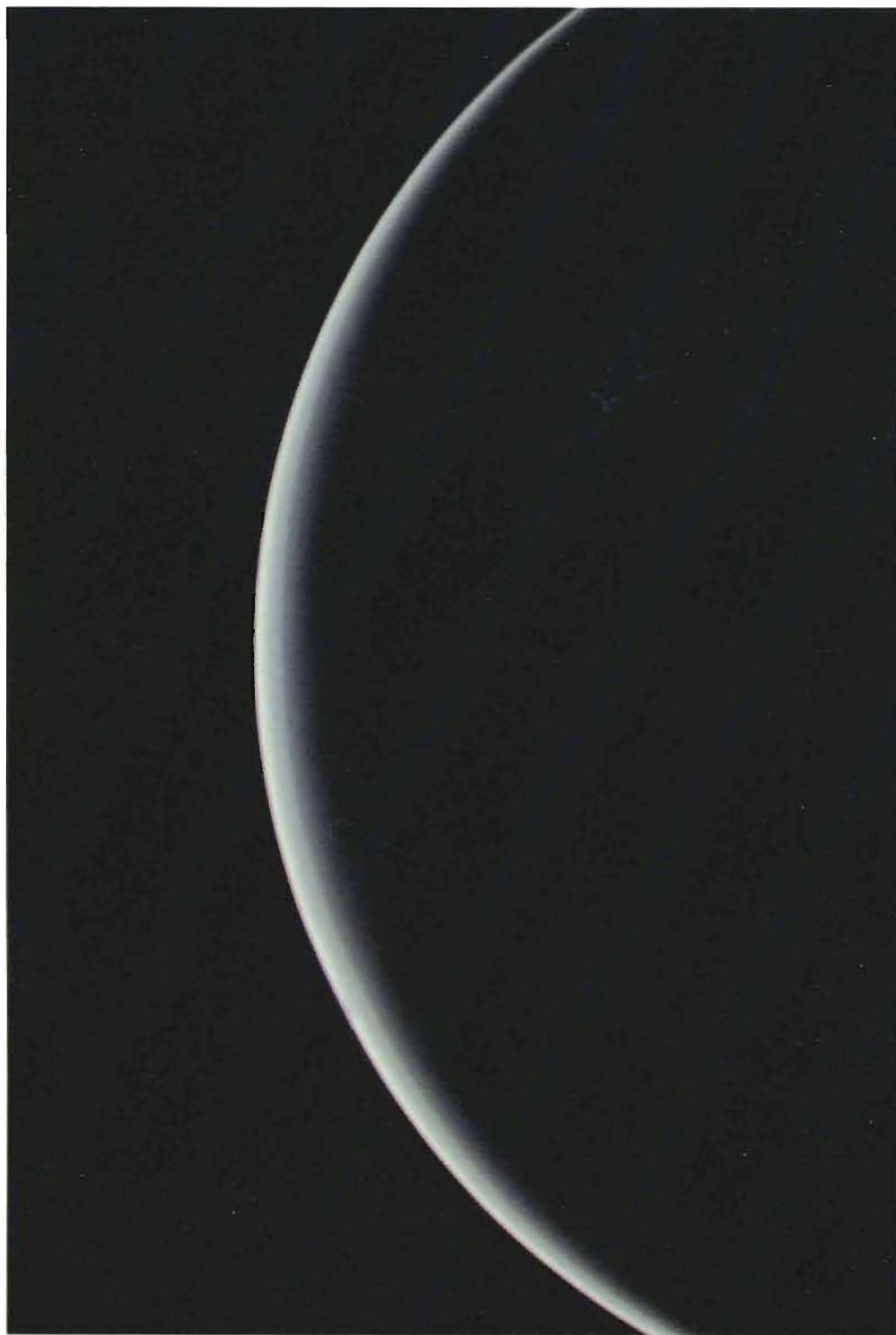
PROPULSION

LABORATORY

1985

Annual

Report



Cover: Voyager 2

was one million
kilometers beyond
Uranus and on course
for Neptune when the
wide-angle camera
took this photograph of
Uranus on January 25,
1986. The picture is
a composite of three
images, taken
through blue, green,
and orange filters.
Uranus' pale blue-
green color, noted by
ground-based
observers and
recorded in earlier
Voyager photographs,
comes from the
presence of methane
in the atmosphere,
which absorbs red
light.

CONTENTS

<i>Director's Message</i>	2
<i>Introduction</i>	4
<i>Flight Projects</i>	6
<i>Space Science</i>	18
<i>Geodynamics</i>	28
<i>Materials Science</i>	32
<i>Advanced Technology</i>	36
<i>Defense and Civil Programs</i>	42
<i>Telecommunications Systems</i>	48
<i>Institutional Activities</i>	56

A description of work accomplished under a contract between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1 through December 31, 1985

JET PROPULSION LABORATORY

*California Institute of Technology
Pasadena, California*

DIRECTOR'S MESSAGE

In 1985, the Voyager 2 Uranus encounter began and the Galileo spacecraft was shipped to Kennedy Space Center. The Galileo and Ulysses spacecraft were prepared for launch to Jupiter and the Sun.

Many of our plans, however, will have to be postponed as a result of the loss of the space shuttle Challenger, which also will affect many of NASA's other space plans. We still are evaluating near-term and long-term options for our JPL space-exploration and space-science missions, confident that the nation's goals in space will be met.

The next launch opportunity for Ulysses and Galileo will be in the middle of 1987. Magellan and the Mars Observer missions may be affected also, but we will make every effort to maintain the current schedule.

Meanwhile, the Laboratory has other significant ongoing activities. In 1985, we accomplished a series of science experiments on the space shuttle. They are described in this report.

We are reasonably confident that TOPEX will become a new start in 1987. We expect the Comet Rendezvous Asteroid Flyby to be the next planetary mission. The recent emphasis on deficit reduction and response along those lines by Congress, however, have concerned us. But JPL is already a major participant in a wide range of special science activities. A few examples are TOPEX, the NASA Scatterometer, and follow-on instruments for the Hubble Space Telescope, whose launch was also delayed. We are working on robotics and automation technology for the Space Station and on several experiments that will be carried out, first in the shuttle and later aboard the Space Station.

The Laboratory will continue to maintain about 25 percent of our resources in the field of Defense and Civil Programs. Several challenging activities apply technology from NASA programs to defense and civil problems. At the same time that work allows us to develop even further technology of importance to space exploration. Examples, also described in this report, include ASAS/ENSCE and the Space Reactor Power System (SP-100).

In 1985 we reexamined our technical base to emphasize progress in technologies critical to space exploration. This reexamination has led us to identify specific areas for emphasis that include the Advanced Microelectronics Program, automation and robotics with its direct application to the Space Station, and optics, including the Large Deployable Reflectors and space communications and investigation. As reported here, progress in these areas has been rapid and rewarding.

With all of the work that has been going on, we are somewhat overcrowded. Parking is a difficulty that is being addressed. Several construction projects have been either



recently completed, are in progress, or are being planned. The Laboratory is very busy—an indication of a vibrant organization that is involved in exciting programs.

Several projects and tasks involve excellent people from both Campus and JPL. We have experienced good interaction with Campus. I am delighted to report that we have increased our discretionary funds, drawing on both the Director's Discretionary Fund and the Caltech President's Fund to support innovative ideas and encourage investigations that will benefit the space program and the entire nation.

The past year saw a change in leadership within the Caltech Trustee Committee on JPL. This group, which has become an important element in Campus-Laboratory relations under the active chairmanship of Mrs. Mary L. Scranton, is continuing to lend its support under its new chairman, the Honorable Shirley M. Hufstedler.

In closing, I want to stress that 1985 was an active year with much progress, accomplished through the energy of our people.

A handwritten signature in dark ink, reading "Lew Allen". The signature is fluid and cursive, with the first name "Lew" and last name "Allen" clearly distinguishable.

*Lew Allen
Director*

T

he Jet Propulsion Laboratory, a division of the California Institute of Technology, is a federally funded research center under a contract with the National Aeronautics and Space Administration. The people of JPL share a common objective: to perform research and development in the national interest.

JPL has three institutional characteristics that shape its philosophy, mission, and goals:

As a part of Caltech, JPL aims for the highest standards of scientific and engineering achievement. Excellence, objectivity, and integrity are JPL's guiding principles.

As NASA's lead center for exploration of planets, JPL has been at the forefront of U.S. lunar and planetary exploration since the space age began. In addition, the Laboratory performs a variety of other research, development, and spaceflight activities for NASA and other government agencies.

As a federally funded research and development center, JPL helps the nation solve technological problems. The Laboratory maintains a strong technology base and does not perform work that should be done in the private sector.

The Laboratory's primary mission evolved from pioneering rocketry research through guided-missile work to spaceflight projects for NASA. Today, JPL is a preeminent national laboratory with an annual budget of \$650 million and a work force of more than 5,000 people.

JPL built and launched the first American satellite, Explorer 1. Since then JPL flight projects have included the Rangers and Surveyors—pathfinders for the Apollo manned Moon landings; the Mariners to Mercury, Venus, and Mars; the Vikings to the surface of Mars; and the Voyagers to Jupiter, Saturn, and Uranus.

When national policy dictated energy self-sufficiency, JPL stepped in with research and development in such fields as solar photovoltaics, solar thermal, and electric-powered vehicles. Today's emphasis on new defense efforts is being answered by JPL in a number of fields that are described in this report.

The year reported on here, 1985, was a period of hard work, accomplishment, and progress. It was a year of preparation for 1986. It was also a year of great strides in diversified fields of technology: new computer architecture, studies of the Earth, robotics and machine intelligence, biomedical applications, and astrophysics.

INTRODUCTION



Still, the Laboratory's major role continues to be exploration of the solar system, including planet Earth. JPL is conducting several programs in Earth sciences and is pressing technology to expand space observations of our climate system.

The year just ended has been an exciting period and the years to come will be still more so.

FLIGHT PROJECTS

VOYAGER

ICE

GALILEO

ULYSSES

TOPEX

MAGELLAN

MARS OBSERVER

PLANETARY OBSERVERS

MARINER MARK II

LARGE DEPLOYABLE
REFLECTOR

MANNED MARS MISSIONS

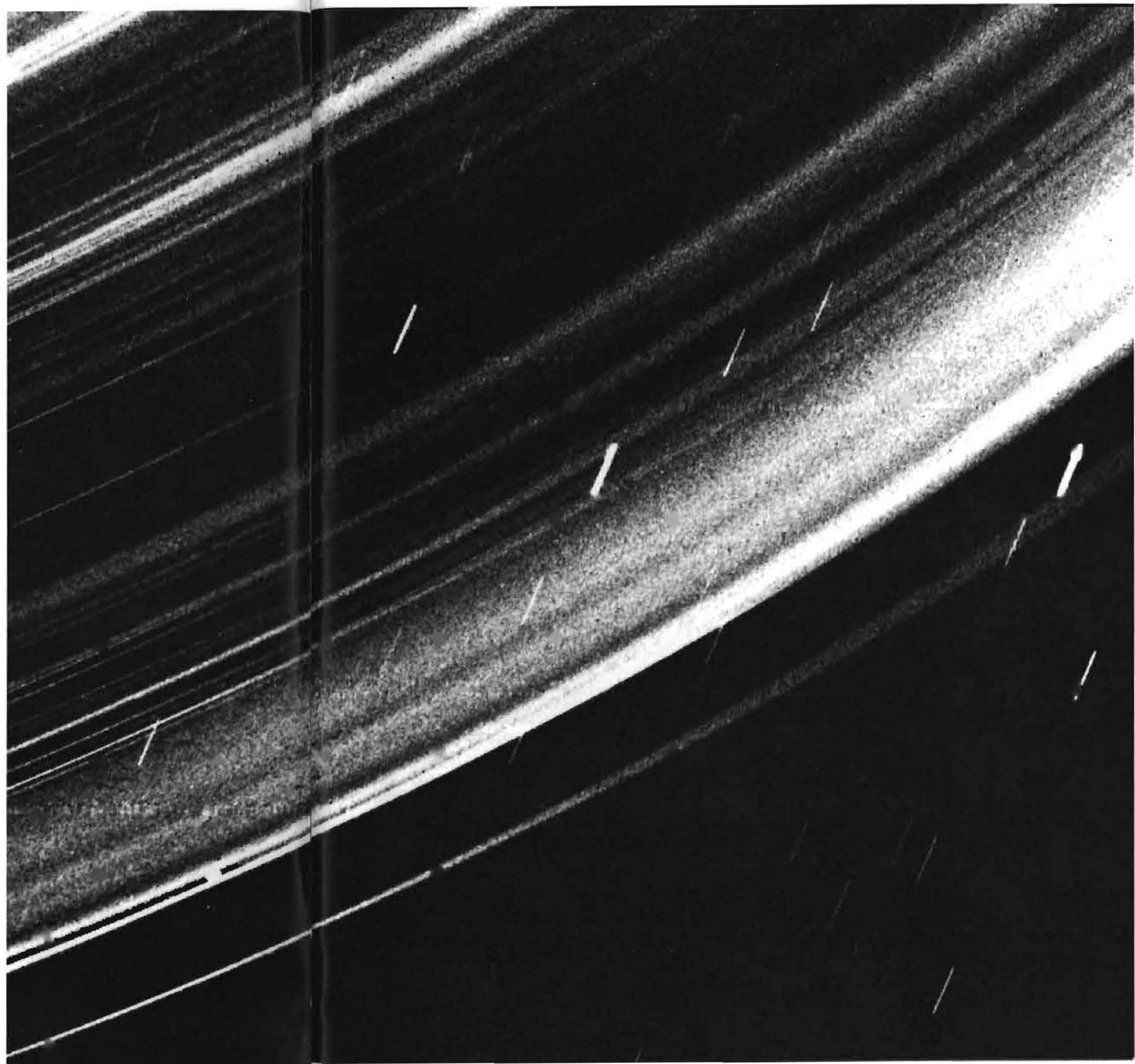
SPACE STATION

EARTH-OBSERVING
SYSTEM

Flight projects are the Jet Propulsion Laboratory's primary work for NASA. The Laboratory has sent spacecraft to all of the inner planets and to three outer planets—Jupiter, Saturn, and now Uranus. Missions such as the Mariners, Vikings, and Voyagers have brought to the nation and the world astonishing views of new worlds that we had known only slightly, from dim views through Earth-bound telescopes. These flight missions have provided us with new knowledge about the universe and where Earth's inhabitants fit into it.

Voyager, which has already returned a wealth of information about Jupiter and Saturn, began its encounter with Uranus in 1985. This was the first close-up exploration, using mankind's tools, of the first planet discovered with mankind's tools; all of the planets closer to Earth had been seen with the unaided eyes of the ancients, but it took William Herschel and his great telescope to find Uranus.

While Uranus required a telescope to reveal itself, comets needed no such technology.



While it was behind Uranus, Voyager 2 took this backlit photograph of the planet's unusual rings on January 24, 1986. Space between the nine previously known rings is filled with tiny dust particles that forward-scatter the sunlight. The ubiquitous dust had never been seen before. The streaks are light from distant stars that appear to move during the 96-second exposure.

Once considered harbingers of disaster, comets today are sought after by scientists who think of them as vital data banks about the beginning of the solar system. In 1985 JPL participated, with NASA's Goddard Space Flight Center, in mankind's first close look at the magnetic field of one of these icy objects, Comet Giacobini-Zinner.

VOYAGER

Voyager 1's planetary encounters are complete and the spacecraft continues to cruise through space, searching for the edge of the Sun's magnetic influence.

Meanwhile, Voyager 2 began the Observatory Phase of its Uranus encounter on November 4, 1985, and passed closest to the blue-green planet on January 24, 1986. The encounter was the first exploration of the seventh planet and its rings and satellites. Voyager 2 also found an unusual magnetosphere at Uranus.

When it reached Uranus, Voyager 2 had been in space for more than eight years. The flight team had spent several years preparing for the unique problems of observing Uranus with a spacecraft that has had several significant problems since launch. That challenge led the flight team to unique solutions to mission design and mission operations.

The project and the Deep Space Network (DSN) had undertaken a major reshaping of Voyager's end-to-end data system since Voyager 2's encounter with Saturn in 1981.

During the Uranus encounter, the DSN's three-station Australian complex was arrayed with the Australian Parkes Radio Observatory. The spacecraft, too, had been reconfigured to permit transmission of images of equal fidelity with one-half to one-third the number of bits received from Voyager at Saturn. A key to the added capability was the first use of Reed-Solomon coding in a planetary mission.

As Voyager moved farther from the Sun, light that was reflected from imaging targets decreased. The lower light levels meant longer exposure times were necessary; in turn, longer exposure times meant greater image smear would occur because of spacecraft motion. As a result, several smear-reduction techniques were used at Uranus, and more drastic measures are being considered for Neptune.

Those problems, plus others such as round-trip communication times that are almost as long as a tracking pass, led the flight team to adopt new and frequently unusual operational strategies.

Nevertheless, the Uranus encounter began as scheduled. Unlike its approaches to Jupiter and Saturn, Voyager 2's approach to Uranus was toward the planet's south pole, which now points sunward. Therefore, the cameras could see only Uranus' south pole and could see little at low latitudes. In images returned as recently as December, little structure could be seen in the Uranian atmosphere—no brightly colored bands or large storms such as those seen at low latitudes on Jupiter and Saturn. All five known satellites had been imaged, as well as Uranus' epsilon ring. As the encounter progressed, Uranus remained a mysterious planet.

INTERNATIONAL COMETARY EXPLORER

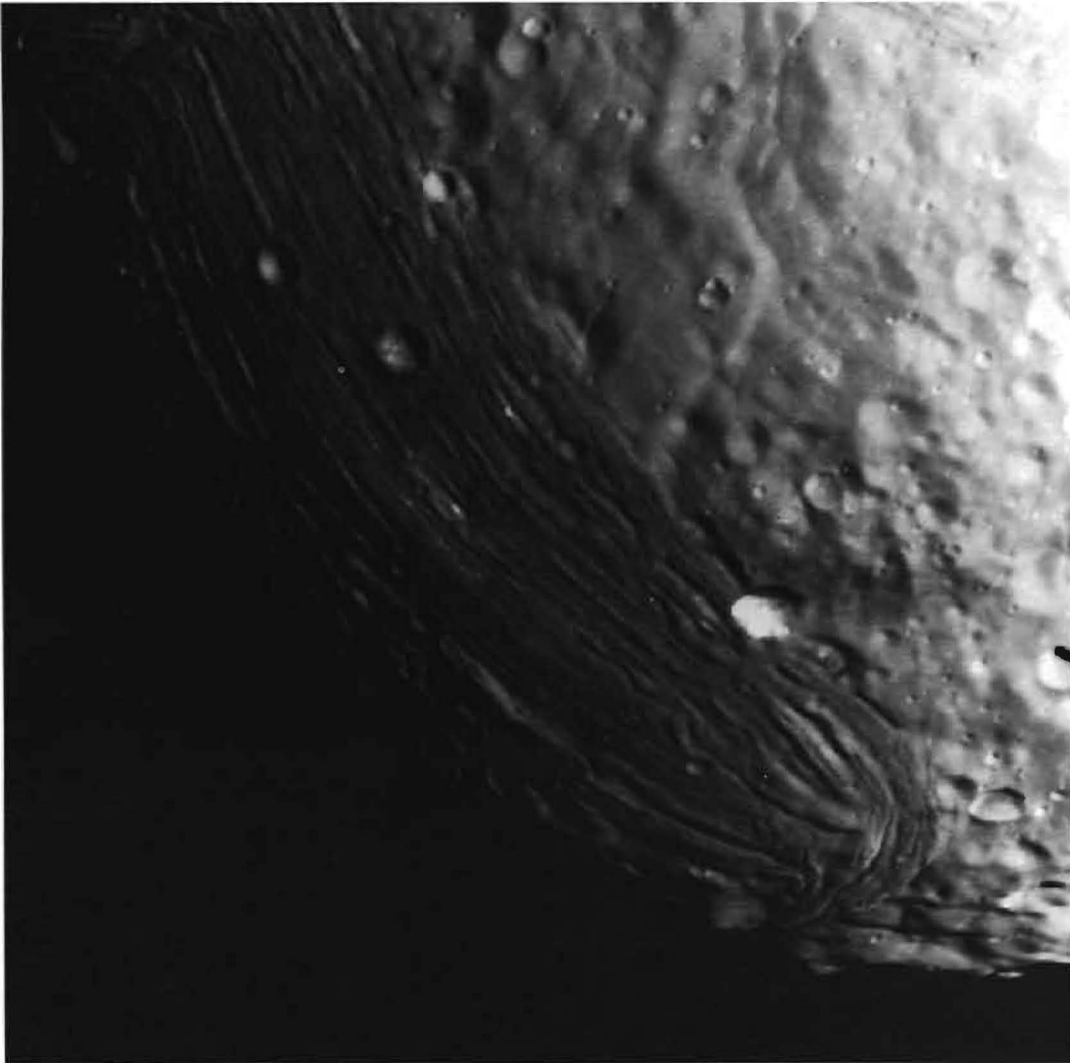
A JPL magnetometer flew through the tail of a comet during the intercept of Giacobini-Zinner by the International Cometary Explorer (ICE) on September 11, 1985. The magnetic-field observations confirmed that the thin tail had been penetrated approximately 8,000 kilometers downstream of the comet's center. The observations—the first of their kind—contain essential information regarding development and structure of the magnetic tail, a characteristic feature of comets. Cometary tails result from the draping of interplanetary magnetic fields around the comets.

The observations also provided information on the interaction of the comet with the solar wind. The interaction leads to formation of a bow wave, which accompanies the comet through space and inside of which the magnetized solar wind is extremely turbulent. The spacecraft survived the encounter intact and is expected to assist in studies of Comet Halley by observing the solar wind before it reaches the comet.

Meanwhile, planning and preparation for other flight projects goes on at JPL so that space science will continue to provide new knowledge and understanding.

Uranus' satellite

Miranda showed a complex geologic history to Voyager 2 on January 24, 1986. At the left is apparently ancient, cratered terrain—rolling, subdued hills and degraded craters. At the center is young, grooved terrain. Along the terminator (shadow line) is complex terrain—intersecting ridges and troughs truncated by grooved terrain.



Technicians prepare the Galileo spacecraft for tests in JPL's thermal-vacuum chamber. The testing simulates conditions Galileo will experience during its flight to Jupiter.



GALILEO

Galileo will use a shuttle and Centaur to boost the 2,570-kilogram spacecraft into interplanetary orbit.

Key events on the spacecraft (Orbiter and Probe) in 1985 started with completion of spacecraft environmental testing followed by a series of three more system-test phases and final burn-in of electronic subsystems. Significant electronic problems were discovered, requiring intensive rework during December and beyond. The radioisotope thermoelectric generators (RTGs) were completed. A preship review was held in mid-December and then the spacecraft and ground-support equipment were transported to Kennedy Space Center (KSC). Launch preparations at KSC began in January.

Both ground and flight software were developed and tested. A major phase of the flight software activity was the development of fault-protection sequences that, in the presence of spacecraft faults, will permit completion of critical sequences such as Probe data return and Jupiter Orbit Insertion (JOI), and will also keep the software in a safe condition during non-critical activities.

The final interplanetary trajectory design was completed. It allows for a possible flyby of an asteroid, release of the Probe 150 days before the Orbiter arrives at Jupiter, an Io encounter just before Probe entry into the Jovian atmosphere, and Jupiter Orbit Insertion. The Probe mission will be tracked by the Orbiter for 75 minutes after Probe entry.

Another unique feature of the trajectory is that it will, for the first time in interplanetary flight, use a broken plane maneuver. This maneuver will take place about two months after nearest approach and will occur at approximately 200 meters per second.

Also completed in 1985 was the final selection of the Orbiter Tour. The 22-month tour allows for ten targeted encounters of the Galilean satellites at distances ranging between 200 and 6,400 kilometers and a number of untargeted encounters at greater distances. Io will be encountered once, just before JOI, Ganymede will be encountered five times, Callisto two times, and Europa three times.

JPL has overall project management responsibility, designed and built the Orbiter, and will direct the flight. The Probe was developed by Ames Research Center. The retro-propulsion module (RPM) was furnished by Bundesministerium für Forschung und Technologie as a joint international venture with the Federal Republic of Germany.

ULYSSES

Ulysses will explore the poles of the Sun. To reach high solar latitudes, the spacecraft must first go out to Jupiter and use that planet's gravity field to boost the spacecraft far from the ecliptic plane.

The Ulysses spacecraft, built for the European Space Agency (ESA) by Dornier Systems of West Germany, was removed in March 1985 from 15 months of storage and began subsystem integration. The nine instruments—six are sponsored by the United States—were refurbished, redelivered, and reintegrated on the spacecraft

in April. The first experiment-integrated system test was completed in July. The spacecraft completed a thermal-vacuum-test magnetic verification, a follow-up integrated system test, and a data review. Recertification was finished when the preshipment review, held at the European Space Research and Technology Center (ESTEC) in September 1985, ended. The spacecraft was shipped to KSC in January 1986.

JPL completed work on several pieces of hardware, including the propellant cart, the RTG cooling cart, and the NASA adapter, which joins the ESA spacecraft to the General Dynamics mission-peculiar adapter mounted on the Centaur upper stage. A separation test was completed in March 1985.

Assembly of the RTG was completed at Mound Laboratories in Miamisburg, Ohio. The RTG is in storage until shipment to KSC.

A joint NASA/ESA review of the Mission Operations System was completed in September. The ESA operations hardware and software were shipped to JPL and are being integrated into the JPL institutional system. Ground data system test activities have proceeded on schedule.

Two major program decisions were reached in 1985: A space shuttle will fly the Ulysses mission with a 104-percent throttle setting to a parking orbit of 110 nautical miles. Sufficient performance margin exists to launch with full Centaur tanks, allowing the spacecraft to reach the highest possible solar latitude and spend the maximum amount of time above 70 degrees solar latitude. The project's Joint Working Group decided to tar-

get the mission to the Sun's south pole first.

All equipment and personnel were in place at KSC in early January 1986 to begin final preparations for launch.

OCEAN TOPOGRAPHY EXPERIMENT

The Ocean Topography Experiment (TOPEX) is a proposed fiscal 1987 new-start project that would use altimetric measurements of the sea surface to map the circulation of the world's oceans. The Earth-orbiting satellite would be launched, at the earliest, in 1991. It could be retrieved by a space shuttle.

A joint working group report, which formalizes the NASA/Centre National d'Etudes Spatiales (CNES) roles in the mission, was published in 1985. The mission is collaborative with CNES, the French space agency, which also intends to perform ocean experiments. The joint mission is called TOPEX/Poseidon, and the satellite is planned for launch aboard a French Ariane booster.

The development of a two-channel-altimeter advanced technology model was completed in 1985, and the gravity-field improvement program continued. A draft of the TOPEX/Poseidon Science Opportunities Document was developed during the year. Three aerospace firms—Fairchild Industries, RCA Corporation, and Rockwell

International—have completed satellite-retrievability studies. Satellite interface descriptions for the sensors and launch vehicle were finalized in preparation for the process to select a single satellite contractor from Fairchild, RCA, or Rockwell.

MAGELLAN

The Venus Radar Mapper project (VRM) received a new name in December 1985—Magellan. The project, which will map the surface of Venus with an imaging radar, continued progress in 1985 toward a launch in April 1988. Important milestones met in 1985 include a design review of the spacecraft in October, a design review of the radar sensor system in October, and a second design review of the radar sensor system in December.

Magellan will obtain data needed to understand the geological processes that formed Venus' surface and the processes that are active in the planet's interior. The primary scientific experiment is an imaging radar, which will produce surface radar images showing features as small as 150 meters across on the cloud-covered planet.

In addition, a radar altimeter will measure the topographic relief of the planet, to aid in interpretation of the radar images.

Magellan will provide the first clear and detailed look at the surface of Venus, the planet nearest Earth and most similar in size, mass, and mean density. Venus holds important clues to understanding the processes that formed Earth and its atmosphere.

MARS OBSERVER

The Mars Observer is the first of the Planetary Observers—a series of low-cost, modestly scoped missions to explore the inner solar system. The Planetary Observer program was submitted as a new start in the fiscal 1985 budget, but only the Mars Observer received approval.

Planning for the Mars Observer has been ongoing since 1982, when it was known as the Mars Geoscience/Climatology Orbiter. A contractor will provide an Earth-orbiting spacecraft of an existing design, modified for the mission. JPL will acquire the scientific instruments, the payload-data subsystem, and a new X-band transponder, and will supply them to the contractor for integration with the spacecraft and launch vehicle.

Launch will take place in August 1990, using the Space Transportation System and an upper-stage intermediate between the Centaur and the PAM-D. After a year-long flight, the spacecraft will be placed in a low-altitude orbit at Mars. The scientific mission will last at least one Martian year (687 days) and will map and characterize the surface and atmosphere of the planet.

In April, NASA issued an Announcement of Opportunity (AO) inviting proposals for experiments and instruments. An AO briefing was held in Pasadena in May, and NASA received proposals early in August.

Evaluation of the proposals is in process, and NASA expects to select the science payload in February 1986. Also in 1985, a unique approach was devised and implemented for procurement of the flight system (spacecraft and upper stage). In June, JPL issued the Request for Proposals (RFP). The RFP allows three types of proposals: a spacecraft, an upper stage, or an integral combination of spacecraft and upper stage. The RFP will permit NASA's Marshall Space Flight Center to award a contract for the upper stage when JPL selects a flight system that consists of a spacecraft and an upper stage. JPL will award the contract for the spacecraft in this case, or for the integral spacecraft/upper-stage combination if that configuration is chosen. Proposals were received in August and evaluated. Selection was due in January 1986.

Last April a prototype of a high-efficiency passive radiator was successfully tested in a helium-cooled vacuum chamber. A flight-like radiator was fabricated and is now in vibration and acoustic testing. Development of the lightweight, compact radiator will provide a method of cooling the scientific instrument detectors and electronics with significant savings in overall mass and volume.

PLANETARY OBSERVERS

After the Mars Observer mission, future Planetary Observers will use the initial spacecraft and operational capability to expand the exploration of bodies in the inner solar system. The following three missions were

studied in 1985 as candidates for the next Planetary Observer:

- ☆ Lunar Geoscience Observer (LGO) to globally map the surface of the Moon from a low-altitude polar orbit about the Moon.
- ☆ Near-Earth Asteroid Rendezvous (NEAR) to globally map the surface of an asteroid from a low-altitude polar orbit about the asteroid. Selection of the asteroid will be from those whose orbits come close to Earth.
- ☆ Mars Aeronomy Observer (MAO) to map the upper atmospheric regions of Mars to determine variations caused by diurnal effects, seasonal effects, and interactions with the interplanetary environment.

Three scientific workshops were held at JPL to review the latest mission design and scientific issues with specialists in the scientific community who are interested in each mission. The results of each workshop have been published as an independent scientific report, while the overall study results are contained in a final JPL study report.

MARINER MARK II

Comet Rendezvous Asteroid Flyby

The Comet Rendezvous Asteroid Flyby (CRAF) will be the first of a series of Mariner Mark II missions to the outer solar system. CRAF planning continues based on a revised plan for a flight-project start in fiscal 1988 rather than in fiscal 1987—the basis for planning throughout most of 1985.

Mariner Mark II is a concept for a new generation of low-cost spacecraft for missions to comets, asteroids, and

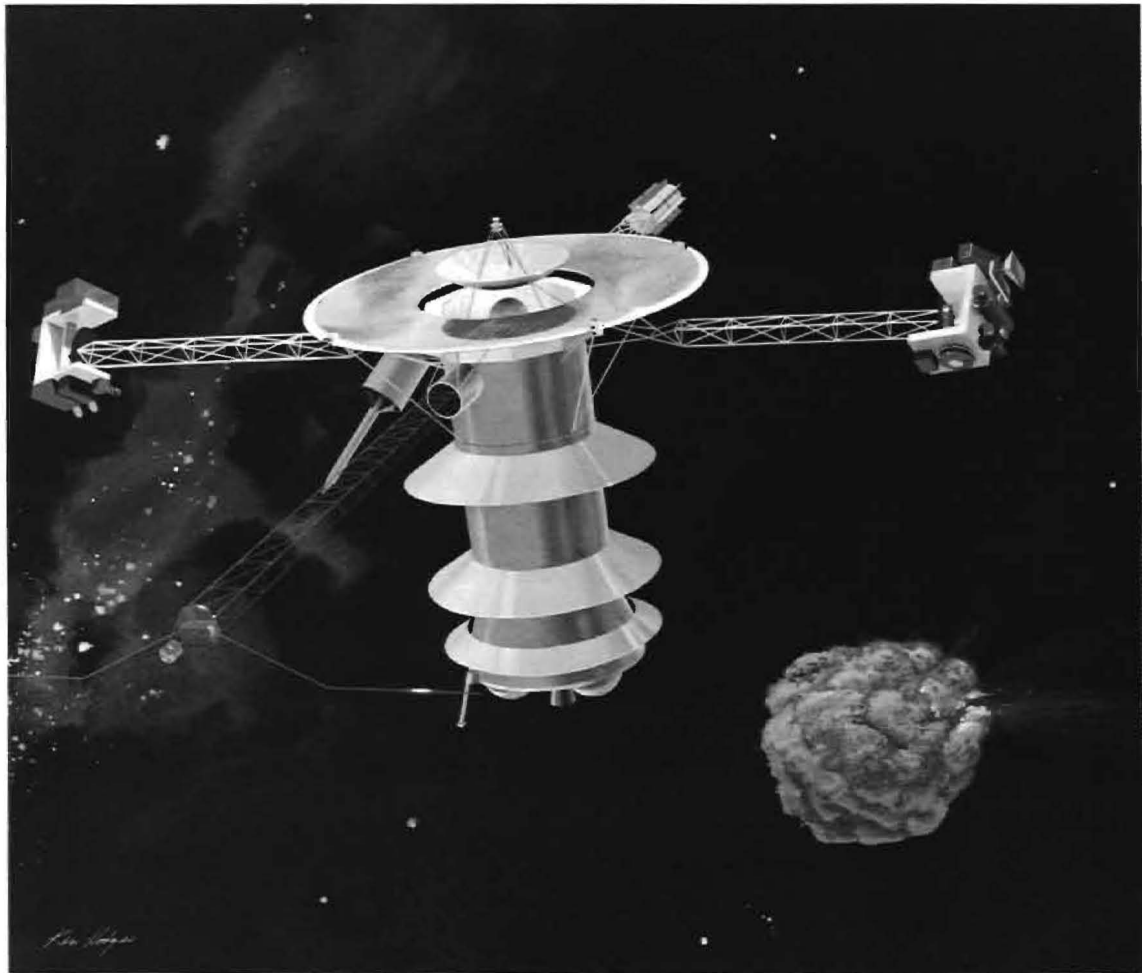
outer planets. The engineering and science requirements for such missions are similar enough that hardware designs and software can be reused in most subsystems.

Consistent with the fiscal 1988 project start, the scientists and mission planners now recommend Tempel 2, a short-period comet that should provide good science return, as CRAF's target. Launch in September 1992 from a space shuttle/Centaur G' combination would place CRAF near Tempel 2 on December 11, 1996, about 1,000 days before perihelion and almost exactly at aphelion. CRAF would fly alongside the comet and collect data for more than three years, until 115 days after the comet and spacecraft had passed the Sun.

The Tempel 2 trajectory would allow the spacecraft to fly past asteroids 1415 Malautra on June 23, 1993 and 46 Hestia (a type F, believed to be a slightly darker carbonaceous chondrite) on January 27, 1995, before the comet encounter.

Advanced technology and development work on selected elements of the spacecraft continued to make excellent progress in 1985. Breadboarding and testing the X-band solid-state power amplifier (XSSPA) for the radio frequency subsystem, the command and data subsystem (CDS), and the scan actuator breadboard are noteworthy examples. All CDS circuitry was designed on a computer-aided engineering (CAE) tool. When the breadboard circuitry was tested, the CDS/CAE-designed circuitry required few modifications. The

This painting shows a major event of the proposed Comet Rendezvous Asteroid Flyby (CRAF) mission—the spacecraft's encounter with a comet far from the Sun. The mission would be the first to use the new Mariner Mark II spacecraft design.



Mechanical Systems Division's CAE system has been used effectively to design spacecraft configurations. The Federal Republic of Germany (FRG) conducted a study of the propulsion module subsystem (PMS). It is planned that the FRG will supply the PMS and at least one science instrument.

NASA released the Announcement of Opportunity (AO) for CRAF science investigations in July 1985. Proposals in response to the AO were received by November 22. The process of evaluation and peer review has started, leading to a tentative selection of investigations in April.

Cassini

A second potential Mariner Mark II mission, to Saturn and Titan, was the subject of a 1985 JPL study. A joint European/U.S. science-study team interacted with technical engineering teams from the European Space Research and Technology Center (ESTEC), the European Space Operations Center (ESOC), and JPL to formulate science objectives and instruments, mission design, and a spacecraft (consisting of a Titan probe and a Saturn orbiter). The European Space Agency would build the Probe, NASA would build the Orbiter, and both vehicles would share the science payload. The combined Orbiter and Probe spacecraft could be launched in May 1994 from a space shuttle/Centaur G' combination and tracked by NASA's Deep Space Network. Probe and Orbiter operations would be conducted at ESOC and JPL, respectively.

Comet Nucleus Sample Return

Return of a pristine core sample from a short-period comet is a major science goal. Many scientists consider cometary material to be the least-modified remnant of primordial solar-system material available and therefore to be vital in understanding the formation and evolution of the planets and other bodies of the solar system. Because even short-period comets have quite elliptical and highly inclined orbits, the round-trip mission has high propulsion requirements and tends to be of several years' duration. Solar Electric Propulsion (SEPs) offers an attractive possibility.

Scientists prefer to approach the comet near aphelion (greatest distance from the Sun) when the comet is inactive in order to land and obtain the sample. Weak sunlight at that distance inhibits the use of SEPs for the final rendezvous and the return. However, use of SEPs as a final kick stage on top of a shuttle/Centaur G' for Earth departure may reduce total mass to a level compatible with a single shuttle launch. To perform the mission with only chemical propulsion would require two shuttle launches and assembly of the spacecraft with two Centaur stages in Earth orbit. Arrival of the returning spacecraft at Earth may use aerocapture to place the sample in a Space-Station-compatible orbit. A major challenge for the entire mission is to develop a way to maintain

the sample at a temperature below 130 kelvins throughout the acquisition and return process.

LARGE DEPLOYABLE REFLECTOR

A study was carried out at the Laboratory during 1985 to develop a new system concept for NASA's Large Deployable Reflector (LDR), an orbiting observatory working in the sub-millimeter wavelength range.

Major features of the observatory are a four-mirror, two-stage optical system; a lightweight, structural-composite, segmented, primary reflector; and a deployable-truss backup structure with an integral thermal shield. The two-stage optics uses active figure control at the quaternary reflector located at the primary reflector exit pupil, allowing the large primary reflector to be passive. The lightweight, composite, reflector panels limit the short-wavelength operation to approximately 30 micrometers, but reduce the total primary reflector weight by a factor of three to four over competing technologies.

MANNED MARS MISSIONS

For the first time in many years, NASA is actively studying manned Mars missions. JPL has been collaborating with NASA's Johnson Space Center and Marshall Space Flight Center in these studies. JPL's contributions are in the areas of planetary science, unmanned precursor missions, mission design, propellant manufacturing from Martian resources, surface rover technology, autonomy, and aerocapture.

The NASA Space Station program's definition phase moved into high gear during 1985 with the award of major contracts to eight contractor teams, including most major U.S. aerospace firms. The program continues to aim for a fiscal 1987 start for development and an Initial Operational Capability in the early 1990s.

JPL made significant contributions during 1985 to the Space Station program in the area of mission requirements definition and analysis. In addition to supporting the Space Station in the analysis of aggregate mission requirements to derive baseline system requirements, the Laboratory conducted detailed technical studies to define the resource requirements of potential Space Station missions, e.g., micro-gravity materials-processing research, staging of planetary spacecraft from the Space Station, and use of the Space Station for assembling and testing the LDR. A significant effort in the autonomy and robotics fields is also under way in support of NASA's Space Station studies.

The Laboratory continued to provide policy, costing, and economics studies, in collaboration with the Caltech Division of

Humanities and Social Sciences as well as with faculty from other universities. A life-cycle model was developed to integrate cost and engineering data across all Space Station subsystems to help guide the design selection process and to estimate the costs borne by Space Station users.

EARTH-OBSERVING SYSTEM

The objective of the Earth-Observing System (EOS) program, managed by the Goddard Space Flight Center (GSFC) for NASA's Office of Space Science and Applications (OSSA), is to establish by the mid-1990s an integrated system of space and ground equipment for carrying out a long-term integrated program of land, ocean, and atmospheric observations.

During 1985, OSSA and GSFC asked JPL to lead the NASA/NOAA (National Oceanic and Atmospheric Administration) convergence study. The objective is to investigate the scientific and technical aspects of using polar platforms, instruments, data streams, and ground systems.

One of JPL's EOS responsibilities is to develop and maintain the roster of possible EOS instruments and their characteristics. During 1985, the Laboratory worked with EOS Science Instrument Working Groups to provide for both individual instruments and integrated platform payloads to the Space Station program's definition contractors.



Planning has begun in earnest for a manned space station—a permanent manned presence beyond Earth's atmosphere—which could be established in the 1990s. (Painting by Paul Hudson for The Boeing Company.)

SPACE SCIENCE

IRAS

COMET OBSERVATIONS

VENUS BALLOON MISSION

ASTEROID RADAR OBSERVATIONS

PLUTO-CHARON MUTUAL ECLIPSE

GIOTTO ION MASS SPECTROMETER

SUBMILLIMETER ASTRONOMY

OBSERVATIONS OF COMETS

DETECTION OF GAMMA RADIATION

DETECTION OF TRANSITIONS

ATMOS EXPERIMENT

MPS

BMLS

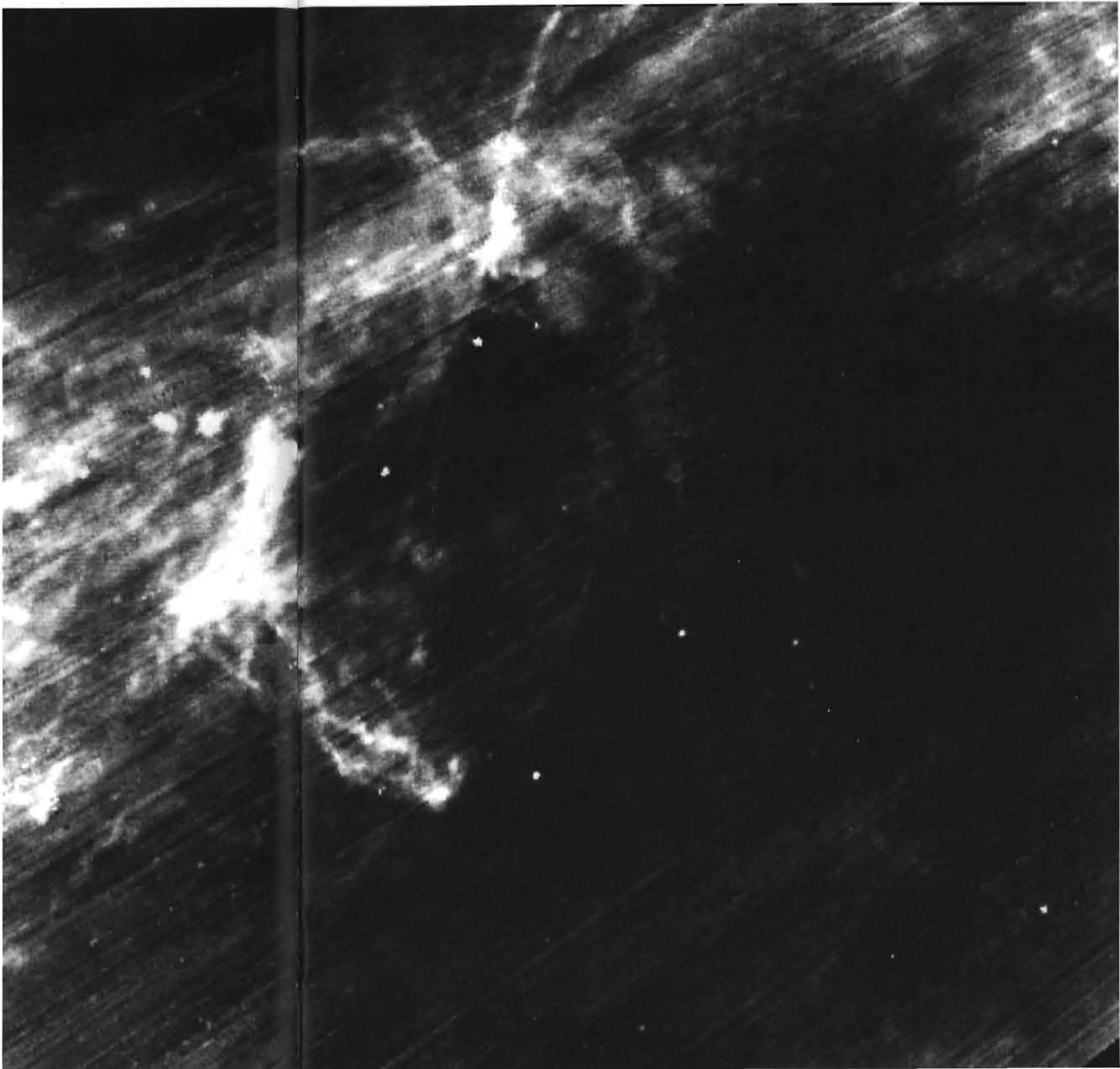
BLISS

OCEANOGRAPHY

GEOLOGY

The end product of flights to other planets is the scientific information they return, the new knowledge we gain from the missions.

We continued our harvest of knowledge from past missions and our preparation for new data to be acquired in 1986. The Infrared Astronomical Satellite continued to provide new answers to old questions and found new questions to be posed. Edmond Halley's comet visited Earth late in 1985, and JPL scientists held a major role in the study, which was to continue into the spring of 1986. New findings came from Voyager data and from instruments that flew in the space shuttle cargo bay.



This 100-micron image, compiled from data sent to Earth by the Infrared Astronomical Satellite, shows a large tenuous cloud of interstellar dust in the Milky Way galaxy. Astronomers are particularly interested in this region because they believe it will help them discover the properties of interstellar dust.

Many astronomers from around the country and the world spent 1985 working with data from the Infrared Astronomical Satellite (IRAS). The data-acquisition phase of the IRAS mission ended in November 1983 when the satellite's liquid-helium coolant was depleted. The primary data-processing phase ended in November 1984 when the IRAS catalog of 245,839 individual point sources and the 212 maps of the sky were released. IRAS had surveyed 96 percent of the celestial sphere.

Spectacular results came from the project. Some of the most important results are described below.

Quasar 3C48 emits ten times more energy than had been previously believed. Almost all of a quasar's luminosity, equivalent to the power of 5,000 billion suns, is emitted at far-infrared wavelengths. While the fundamental energy source of quasars is poorly understood, it is thought that a massive black hole at the center of a galaxy ingests stars and interstellar matter and that a fraction of this gravitational potential energy is radiated away. The nature of galaxies in which quasars are found is not, however, well established. Infrared-bright quasars may be located in spiral galaxies whose plentiful gas and dust convert the radiation from the central object into infrared emission that can be detected by IRAS. Quasars that emit only weakly in the infrared may reside within elliptical galaxies devoid of gas and dust.

The distribution of approximately 20,000 galaxies detected by IRAS was used to determine the gravitational field of all matter within about 600 million light-years of our galaxy. The uniformity, degree of sky coverage, and accuracy of the IRAS catalog permitted astronomers to determine that there are 10 to 20 percent more galaxies than average in the direction of the constellation Hydra. That is approximately the same direction toward which the cosmic 3-kelvin background radiation, the relic of the Big Bang, has been found to be brightest. The apparent excess of galaxies in that direction could pull our local group of galaxies, thereby causing the observed anisotropy in the background radiation field. While the results are still controversial, it is significant that IRAS observations address basic cosmological questions. This result, when confirmed by a careful analysis of the IRAS data combined with a redshift survey of those galaxies, could ultimately lead to the determination of whether the universe is open or closed.

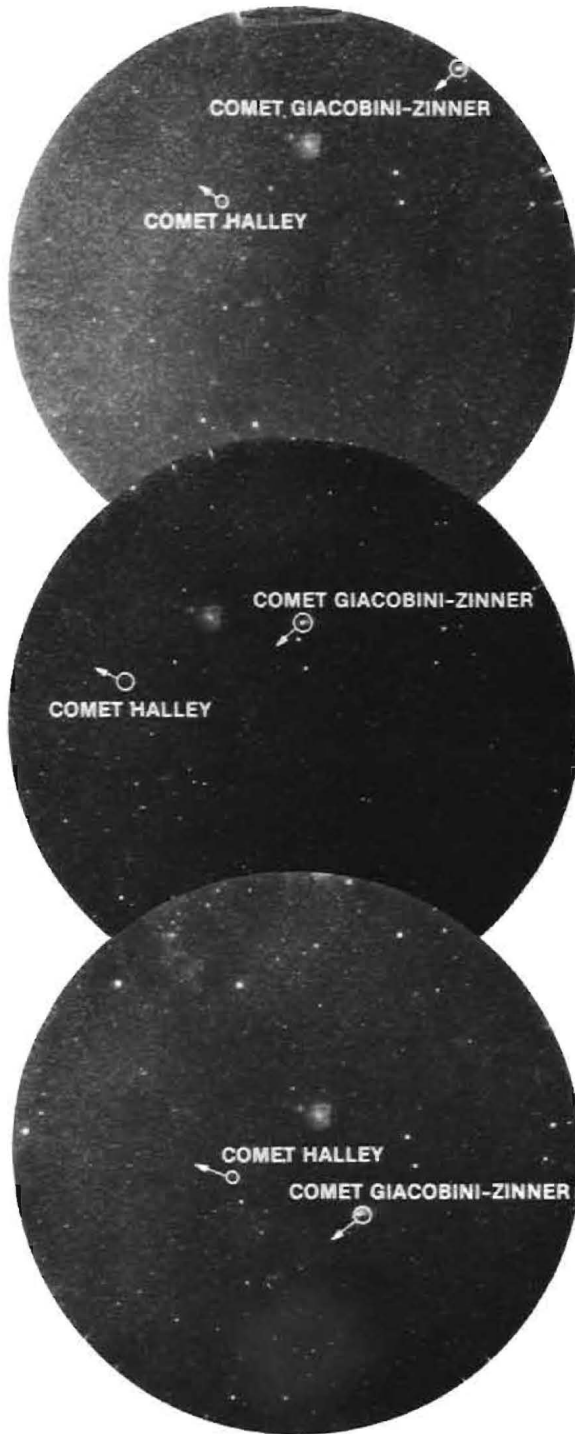
Dozens of stars, whose mass is much like our own Sun's, have been found forming in nearby interstellar clouds. Protostars—stars still deriving their energy from infalling interstellar matter—have long been sought by infrared astronomers. IRAS observations of compact clouds in the constellations Taurus and Ophiuchus revealed sources that are among the best candidates for accreting protostars. Conditions in these objects are probably similar to those around our own Sun when the planets condensed out of the primitive solar nebula more than four billion years ago.

As an outgrowth of the IRAS project, NASA, JPL, and Caltech set up the Infrared Processing and Analysis Center (IPAC) to continue processing IRAS data and to serve the needs of U.S. astronomers wanting to work with the staggering amount of new information about the infrared sky. Among the processing tasks IPAC completed in 1985 was a catalog of some 16,000 small extended sources consisting of, for example, large galaxies, regions of star formation, and stars with shells around them. Also 6,000 new images of roughly degree-sized fields were released to the astronomical community. The data were taken by the satellite in a special pointed mode that gave enhanced sensitivity and spatial resolution compared with the basic survey.

Several ambitious new projects began as well. One of the most important is the reprocessing of most of the 40 billion bytes returned by the satellite to generate a new catalog of point sources three times more sensitive than the just-released catalog. By combining data from IRAS' three separate coverages of the sky during its 300-day mission, it should be possible to detect extremely faint objects. This new catalog will contain observations of 75,000 hitherto unobserved galaxies and tens of thousands of stars. Project scientists hope that the new sensitivity threshold will permit observations of new sorts of objects such as brown dwarf stars—giant Jupiters that have been hypothesized to provide much of the missing mass in the universe—located within a few light years of Earth.

COMET OBSERVATIONS

A rare instance when two major comets seemed to pass each other in space was recorded in a photograph of comets Halley and Giacobini-Zinner, captured by JPL astronomers in mid-September. Giacobini-Zinner, whose brightness at the time was 8th magnitude, resembles a fuzzy streak, while Halley, at 12th magnitude, appears as little more than a slightly blurred point of light. Though the two comets were less than 2 degrees apart—the width of four diameters of the Moon—as viewed from Earth, at the time they were photographed they were in fact nearly 240 million kilometers apart in space as Halley and Giacobini-Zinner continued on their trips toward and away from the Sun, respectively. The event, which astronomers say is unique in the history of sky observation, took place three days after NASA's International Comet Explorer spacecraft encountered Giacobini-Zinner, the first flyby of a comet by an Earth-launched probe.



Three photographs of Comets Halley and Giacobini-Zinner were taken by JPL astronomers using the 48-inch Schmidt Telescope at Palomar Observatory in California. The photographs were taken (top to bottom) on September 12, 13, and 14, 1985.

VENUS BALLOON MISSION

For four days in mid-June 1985, 20 of the world's most sensitive radio observatories directed their antennas toward the planet Venus to receive signals from a pair of meteorological balloons floating in Venus' atmosphere at a mean altitude of 54 kilometers above the planet's surface. The balloons were deployed on June 11 and 15 from the two Soviet Vega spacecraft as they flew by the planet on their way to a rendezvous with Comet Halley in March 1986.

Scientists and engineers from JPL worked with colleagues at Caltech, Ames Research Center, the Centre National D'Etudes Spatiales (CNES) of France, the Academy of Sciences of the USSR, and a global network of radio observatories to conduct the balloon experiment. Data acquired during the 46-hour life of each balloon consist of (1) atmospheric measurements from scientific instruments on the balloon gondolas and (2) measurements of wind velocity (actually position and velocity of the balloon) made by the global network of radio observatories using Very Long Baseline Interferometry (VLBI).

The balloons were placed in the Venus equatorial region, near Venus midnight, and were carried 30 degrees past the morning terminator to the sunlit side of the planet before 18 C-cell-sized batteries that powered the instruments and the transmitter were depleted. Measurements were made of pressure, temperature, relative vertical wind speed, cloud particle density, light intensity, and lightning frequency. The data were radioed to Earth and received at the three 64-meter

antennas of the NASA Deep Space Network (DSN) in California, Spain, and Australia, and at several large antennas in the Soviet Union. The signals were also monitored by radio-astronomy observatories in Brazil, Canada, England, the Federal Republic of Germany, Puerto Rico, South Africa, the Soviet Union, Sweden, and the United States.

The telemetry and tracking data from the DSN and Soviet stations are being analyzed now by the science team composed of representatives from France, the Soviet Union, and the United States. Preliminary results reveal that the mean zonal wind speeds were approximately 69 meters per second for balloon 1, at a latitude near 7 degrees north, and 66 meters per second for balloon 2, at 6.5 degrees south. Zonal velocity variations of several meters per second were observed, with a possible solar-fixed feature in the wind pattern. Short-term balloon-velocity variations indicate that the atmospheric turbulence was greater than had been expected. The balloons also experienced large altitude excursions resulting primarily from downdrafts with velocities of up to 3.5 meters per second. The vertical atmospheric motions persisted up to several hours and may have been induced by variations in surface topography. At a given altitude, the atmospheric temperature showed a nearly constant difference of about 6 kelvins between the two balloons, indicating the balloons were injected into different, long-lived, large-scale air masses.

ASTEROID RADAR OBSERVATIONS

Astronomers from JPL, Arecibo Observatory in Puerto Rico, and Harvard conducted the first extensive radar observations of mainbelt asteroids. The echoes show these objects' surfaces to be smooth at quite small scales but extremely rough at much larger scales. The range of asteroid radar albedos is very broad and implies substantial variations in porosity or metal content (or both). The highest albedo estimate, for the asteroid Psyche, is consistent with a surface having porosities typical of lunar soil and a composition nearly entirely metallic. This 250-kilometer-diameter object might be the collisionally stripped, metallic core of a magmatically differentiated asteroid and is by far the largest piece of refined metal in the solar system.

START OF PLUTO-CHARON MUTUAL ECLIPSE SEASON

The existence of Pluto's large satellite, unofficially named Charon, was confirmed on January 16, 1985, when JPL astronomers, observing from Palomar Observatory in California, detected a 4-percent decrease in the combined brightness of the two bodies. The decrease in brightness was caused by a grazing passage of Charon in front of Pluto as viewed from Earth. The event was confirmed on February 17, 1985, by observations from the McDonald Observatory in Texas. The complementary event, the passage of Charon behind the edge of Pluto, was observed from the Mauna Kea Observatory in Hawaii.

Analysis of these events implies that Charon's radius is between 0.40 and 0.50 that of Pluto's, that Charon orbits Pluto in a circular orbit with a radius between 10.9 and 14.1 Pluto radii, and that Charon's albedo is perhaps 75 percent that of Pluto's. The events also suggest a density of about 0.9 ± 0.3 grams per cubic centimeter for the Pluto-Charon system. The deepest events to be expected during the 1986 apparition will correspond to a drop in brightness of almost 20 percent, about five times the drop in brightness observed in 1985. Those events will occur during each of the next six apparitions of Pluto.

PRELIMINARY RESULTS FROM THE GIOTTO ION MASS SPECTROMETER

The European Space Agency's Giotto spacecraft was launched in 1985, and its instruments were exercised and in-flight tested in preparation for the March 13, 1986, flyby of Comet Halley.

NASA and U.S. co-investigators have made substantial contributions to the development and construction of the high-energy-range spectrometer (HERS) subsystem of the ion mass spectrometer on Giotto. HERS is the outgrowth of several years of instrument development work at JPL. The Giotto ion mass spectrometer was first turned on in space on September 7, 1985, and by early October, the orientation of the spacecraft allowed HERS to observe the solar wind. As the solar wind velocity changed from 300 to 700 kilometers per second, it was possible to check the instrument response and performance over a broad energy range. The instrument is clearly able to resolve the ions, as was hoped.

AIRBORNE SUBMILLIMETER ASTRONOMY

A new cooled dual-frequency heterodyne receiver was built and successfully flown on the NASA Kuiper Airborne Observatory, a C-141 airplane, in March 1985. The receiver operates at frequencies of 183 gigahertz (1.6 millimeters) and 380 gigahertz (0.8 millimeter). These two frequencies were chosen to detect the presence of water vapor in planets, comets, and star-forming regions.

The flight in March mapped the distribution of water in the core of the Orion molecular cloud and searched for water in the atmosphere of Venus. The same heterodyne receiver will be used in 1986 to search for water in Comet Halley.

OBSERVATIONS OF COMETS WITH THE NASA INFRARED TELESCOPE FACILITY

The nucleus of Comet P/Arend-Rigaux was directly detected at infrared wavelengths using the NASA Infrared Telescope Facility at Mauna Kea Observatory in Hawaii. This is only the third cometary nucleus ever observed in the infrared (IRAS-Araki-Alcock was the first). The observed light curve indicates that the nucleus is nonspherical and that its largest diameter is about 10 kilometers. The high temperature means that the surface must be covered with a dark, nonvolatile mantle, supporting the idea that some comets may evolve into asteroids.

DETECTION OF GAMMA RADIATION

JPL scientists made substantial progress in the development of two new techniques for the detection of extraterrestrial sources of nuclear gamma radiation. Such radiation is expected to arise, for example, from the decay of radioactive material produced in supernova explosions and from the de-excitation of surface material after cosmic-ray bombardment of bodies in the solar system.

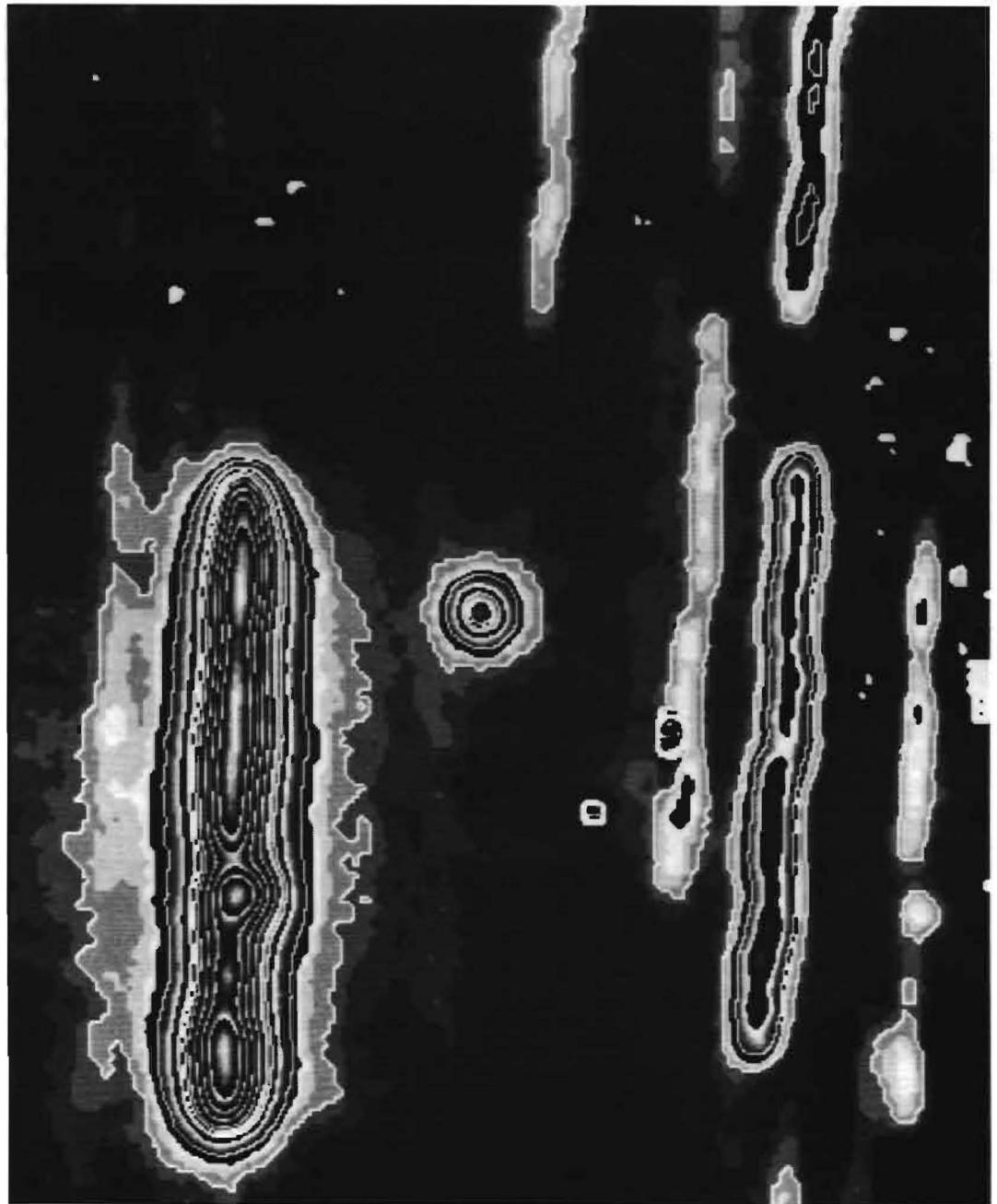
One of the new instruments developed to detect the nuclear gamma radiation has a position-sensitive germanium detector, while the second instrument uses a liquid noble gas. The two instruments use positional information to reduce background counts and to provide gamma-ray imaging capabilities. Operational systems using both techniques were made for the first time in 1985 and promise to provide a substantial improvement in sensitivity over existing systems.

DETECTION OF OPTICALLY FORBIDDEN TRANSITIONS IN ELECTRON-ION COLLISIONS

For the first time anywhere, scientists using the electron-energy-loss approach pioneered at JPL detected in the laboratory excitation of optically forbidden transitions in ions and angular distribution of the measured scattering. The ions studied were magnesium and cadmium.

The results are significant because they show that current detection techniques are sufficiently sensitive to measure the weak signals in electron-ion collision systems. Moreover, the types of transitions studied here (optically forbidden) are the

Canadian and JPL astronomers joined to study Comet Halley with the Canada-France-Hawaii Telescope on Mauna Kea in Hawaii. The circular object at the center of this false-color image is the bare, unresolved nucleus of the famous comet. This photograph was taken while Halley was still beyond the orbit of Jupiter. A comet's nucleus can be studied only when the comet is relatively inactive—at great distances from the Sun.



types used as electron density and temperature diagnostics in solar, stellar, and interstellar absorption and emission spectra. Data such as excitation cross sections have not yet been measured in the laboratory, and astronomers have had to rely on theoretical calculations, which can be in error by factors of 2 to 5. The JPL goal is to continue such measurements in singly and multiply charged ions with a new apparatus having 103 to 104 increased sensitivity for detection of scattered electrons.

ATMOS EXPERIMENT ON SPACELAB 3

The first flight of the Atmospheric Trace Molecule Spectroscopy (ATMOS) instrument was made as part of the Spacelab 3 science payload in April 1985.

The broad purpose of the ATMOS experiment is to investigate the physical structure, chemistry, and dynamics of the upper atmosphere through the study of neutral minor and trace constituent distributions and their seasonal and long-term variations.

The ATMOS instrument is a state-of-the-art Michelson interferometer. A high-resolution infrared absorption spectroscopy uses the Sun as the radiation source to observe changes in the transmission of the atmosphere as the line of sight from the Sun to the spacecraft penetrates the atmosphere close to the Earth's limb at sunrise and sunset. The measurements, which cover the wavelength range from 2 through 16 microns, are made at a spectral resolution of 0.01 wave numbers.

Preliminary analysis of the data has revealed the presence of more than 30 different

molecular species whose concentrations can be measured over altitude ranges that vary, depending on the particular constituent, from the upper troposphere through the stratosphere and mesosphere to the lower thermosphere (approximately 130 kilometers). Several of the trace constituents (for example, dinitrogen pentoxide and chlorine nitrate) had not been detected before with certainty. The stratospheric spectra provide simultaneous measurements of most of the important species in the nitrogen, chlorine, and hydrogen families of molecules involved in the ozone photochemistry of this region; the observations of the mesosphere and thermosphere, which include measurements of methane, carbon dioxide, carbon monoxide, water, and ozone, provide new insights into the photochemistry and dynamics of the region of the atmosphere characterized by dissociation of the minor gases and by the effects of the breakdown of local thermodynamic equilibrium.

In addition, ATMOS returned a sufficient number of high-resolution solar spectra to produce a very high signal-to-noise-ratio solar atlas of the near- and mid-infrared wavelength region. When published, the atlas will show features of the Sun's photosphere and chromosphere that have not been observed before. NASA plans to fly the ATMOS instrument at approximately yearly intervals for the next 10 to 15 years to provide an archival record of the composition of the upper atmosphere and its variability.

MICROWAVE PRESSURE SOUNDER

The ability to make remote measurements of atmospheric pressure at the Earth's surface was demonstrated for the first time by test flights of the microwave pressure sounder (MPS) on NASA's CV-990 airborne laboratory (which was later destroyed by fire).

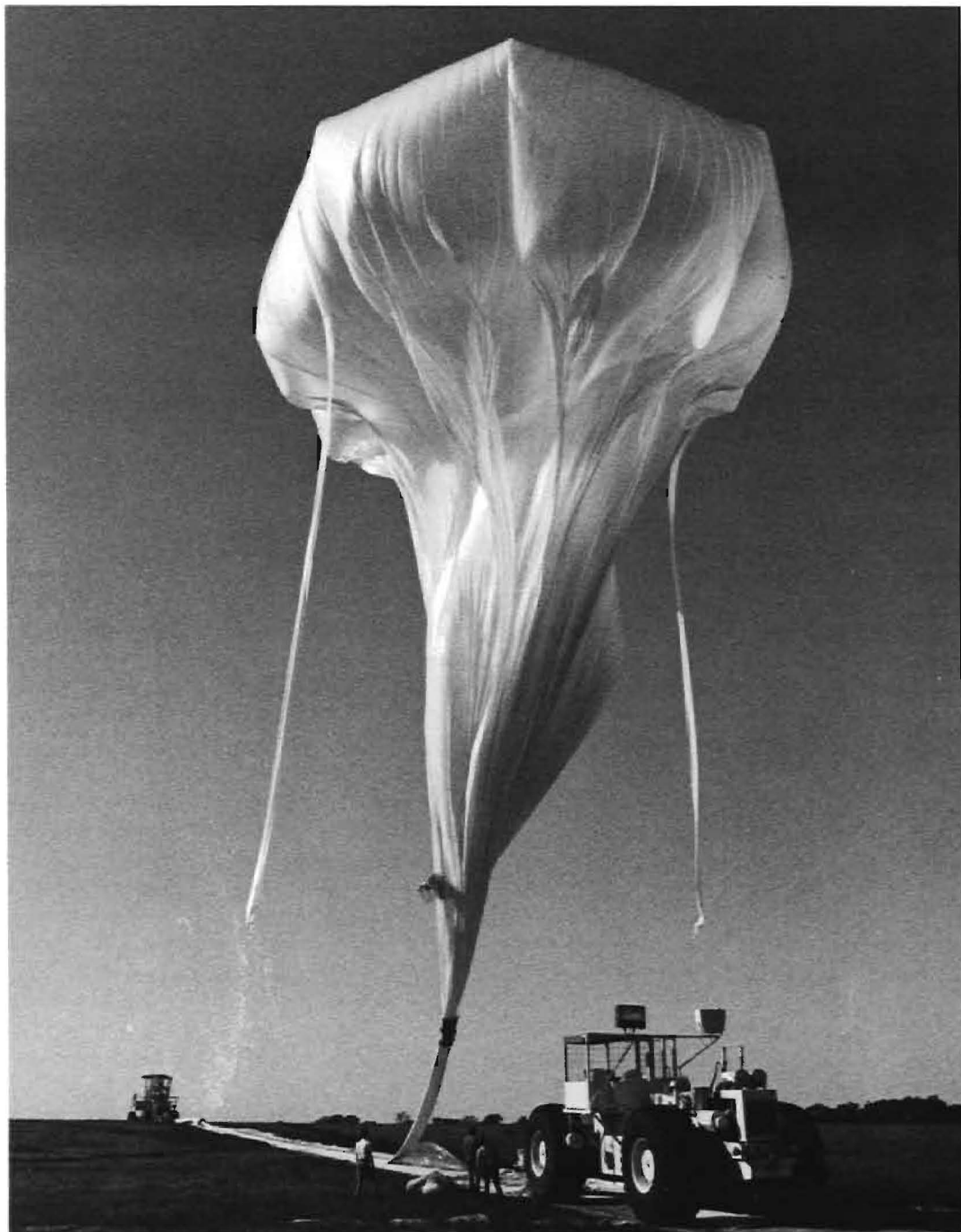
The MPS instrument is a unique millimeter-wavelength radar that measures differential absorption over the vertical atmospheric path from the aircraft to the ocean surface. Data taken from a range of altitudes in a series of flights over the North Pacific Ocean show that the measured signal correlates with the difference between pressure at the aircraft altitude and at sea level to an accuracy of 1 millibar.

BALLOON MICROWAVE LIMB SOUNDER

The first flight of the JPL Balloon Microwave Limb Sounder (BMLS) with a new liquid-nitrogen-cooled radiometer was performed on May 9 and 10, 1985, from the National Scientific Balloon Facility in Palestine, Texas. Data were obtained continuously for 26 hours from a float altitude of approximately 38 kilometers.

BMLS measures thermal radiation from the limb of Earth's stratosphere in three spectral bands near 1.5-millimeter wavelength. The bands cover rotational spectral lines of chlorine monoxide, ozone, and hydrogen peroxide. Vertical profile measurements of these species in the stratosphere can improve our understanding of the chemistry of stratospheric ozone, which shields life on Earth from harmful solar ultraviolet radiation.

Technicians at the National Scientific Balloon Facility in Texas prepare to launch a giant balloon carrying JPL's Balloon Microwave Limb Sounder instrument.



The most important BMLS measurement was of chlorine monoxide, whose understanding is crucial for prediction of stratospheric ozone depletion by products from industrially produced chlorocarbons.

The improved BMLS sensitivity, and the long flight, provided the first detailed measurements of the diurnal variation in the shape of the chlorine monoxide vertical profile.

Scientific interpretation of the new measurements is in progress, and a satellite instrument for these and other measurements is being developed for NASA's Upper Atmosphere Research Satellite (UARS), planned for launch in 1989.

INFRARED DIODE LASER SPECTROMETER

The Balloon-borne Laser In-Situ Sensor (BLISS) uses a new approach to gather data on the composition of the ozone layer of Earth's stratosphere.

At float altitude, about 35 kilometers, a visible laser beam optically tracks a retro-reflector lowered approximately 500 meters below the instrument gondola. With tracking maintained, signals from tunable solid-state diode lasers are bounced off the retroreflector so that long-path infrared absorption measurements can be made to determine the concentrations, at the sub-parts-per-billion level, of several chemically related stratospheric species. This powerful new spectrometer was used to measure nitric oxide, nitrogen dioxide, and water vapor in a November 1985 flight, and can measure many other gases that are coupled to the depletion of stratospheric ozone.

A miniature version of the laser spectrometer is being designed as a candidate instrument on the probe of the NASA/ESA Cassini mission in the 1990s. The instrument would study the organic chemistry of Titan's atmosphere.

OCEANOGRAPHY

Recently, a lot of attention has been given to the far-reaching economic and ecological effects of the 1982-1983 anomalous warming, known as El Niño, of the ocean surface in the tropical Pacific. Understanding the interaction processes between the ocean and the atmosphere that underlie such anomalies was hampered by lack of data. Spaceborne sensors have the potential for providing the required measurements.

Using observations from space, JPL recently developed a method to estimate evaporation from the ocean and the latent heat it carries. Such useful data were derived from observations of the scanning multichannel microwave radiometer (SMMR) on the Nimbus 7 satellite. The change of sea surface temperature depends on the net surface heat flux and heat advection in the upper ocean. Although latent heat flux is only one component of the net surface heat flux, the satellite data clearly demonstrated that the latent heat flux is a dominant factor in governing the change of sea surface temperature, at least in the region of study.

GEOLOGY

Three major activities were under way in 1985 to enhance our ability to observe the Earth's surface by remote-sensing techniques. An airborne visible and infrared imaging spectrometer (AVIRIS) will fly on the U-2 and provide simultaneous high-resolution images of Earth for 224 spectral bands from 0.4 to 2.5 microns. The measurements will be used to develop techniques for surface geologic mapping, surface composition identification, and vegetation assessment. An advanced airborne multispectral synthetic aperture radar (SAR) was also under development to replace the airborne system destroyed in the CV-990 fire. This system will operate at both L-band and C-band frequencies and have quadruple polarization capabilities. The radar is scheduled for completion in early 1987 to support the next flight of the shuttle imaging radar (SIR-B) system on a shuttle.

Both AVIRIS and the airborne radar are precursors for advanced space systems scheduled to fly on a shuttle and the Earth-Observing System. The third activity involves development and operation of a special ground satellite receiving station and a processing center to be used for collecting and processing SAR data from the ESA Earth Resources Satellite, the Japanese Earth Resources Satellite, and the planned Canadian Radarsat Satellite to collect data for studies of the polar sea-ice field. The facility is to be operated by the University of Alaska at Fairbanks.

GEODYNAMICS

PLATE MOTIONS

SECULAR CHANGES

SETI

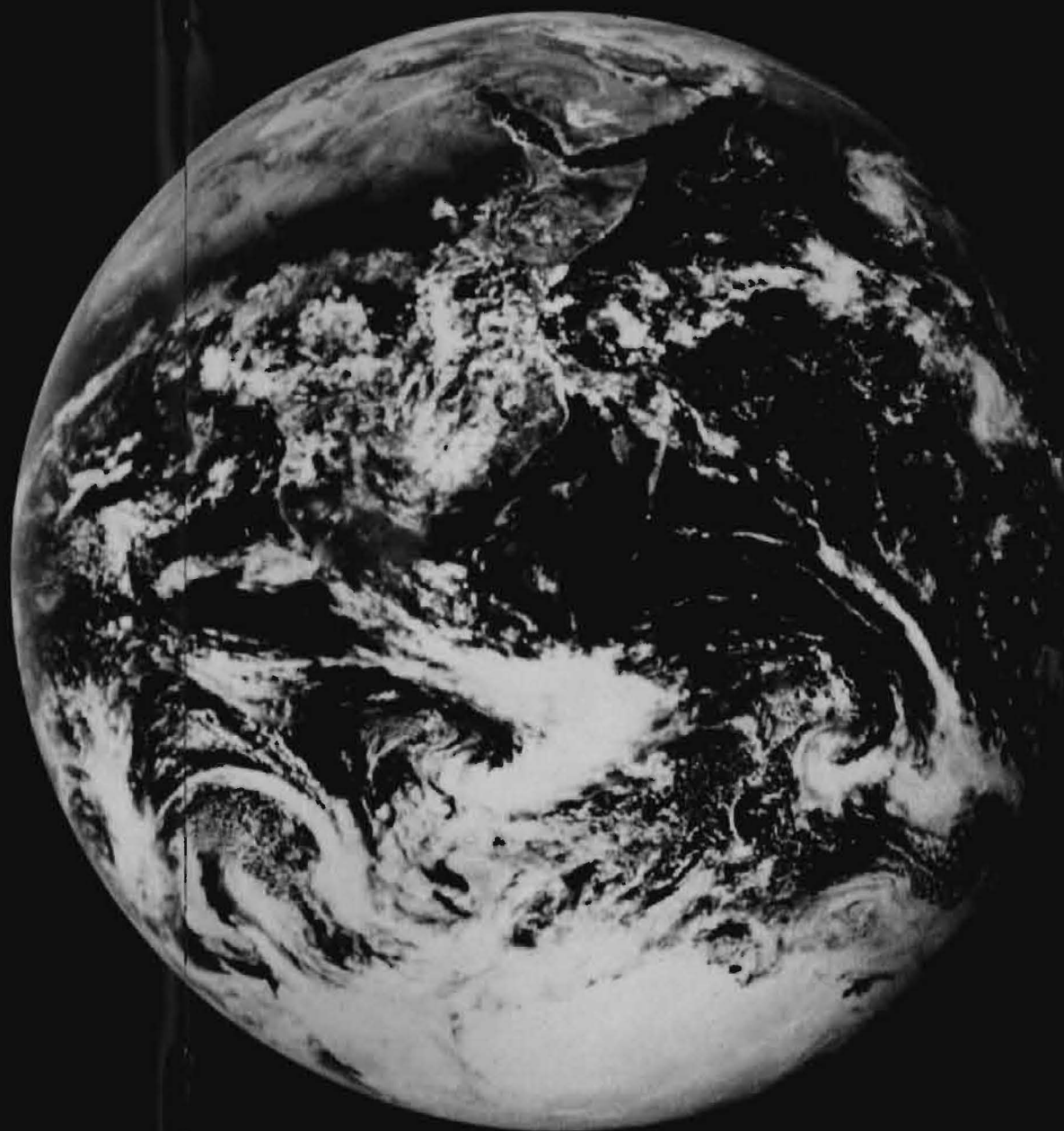
Studies of the ever-changing planet on which we live continued in 1985 with several important discoveries. We made new measurements, with new accuracy, of the Earth's moving surface plates and measurements of basic changes in the shape of our planet.

PLATE MOTIONS AS MEASURED BY MOBILE VLBI

The Mobile VLBI Project at JPL began in 1979 as part of a geodetic surveying program to determine relative motions and regional strain fields near the tectonic plate boundaries in California and Alaska. Some sites have now been measured almost six years.

Moreover, today's single-measurement accuracies in baseline length are often 1 centimeter or better. Consequently, nonzero values for the velocities of several sites on the western side of the San Andreas Fault, with respect to sites on the eastern side, may be emerging above the threshold for detection (e.g., Monument Peak/Quincy and JPL/Owens Valley baselines). Although based on a small number of

The Earth, photographed here by Apollo astronauts while they were en route to the Moon in 1972, is a subject for research at JPL.



30

measurements, the motion observed on the first of the baselines appears to be consistent with geological rates of 5.5 centimeters per year and consistent with measurements determined from independent satellite laser-ranging measurements. One intriguing interpretation of the results is that accumulation of strain between the North American and Pacific Plates is distributed over a broad region, with JPL located within that region.

SECULAR CHANGES IN EARTH'S OBLATENESS

Recently, scientists from JPL and the University of Texas announced detection of a secular change in Earth's oblateness, or J_2 gravity coefficient, from analysis of orbit residuals of NASA's Earth-orbiting Laser Geodetic Satellite (LAGEOS). LAGEOS is a dense, free-flying satellite covered with cubic-corner retroreflectors and is tracked from Earth by the Goddard Satellite Laser Ranging Stations using pulsed laser beams. Recent studies suggest that the apparent change in J_2 results from a combination of at least three sources: (1) post-glacial rebound, (2) rise in sea level caused by present-day glacier melting, and (3) tidal friction in the long-period (18.6-year) zonal tide. The rebound rate depends on the initial size of the great ice sheets, their melting history, and the plasticity or viscosity of Earth.

SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

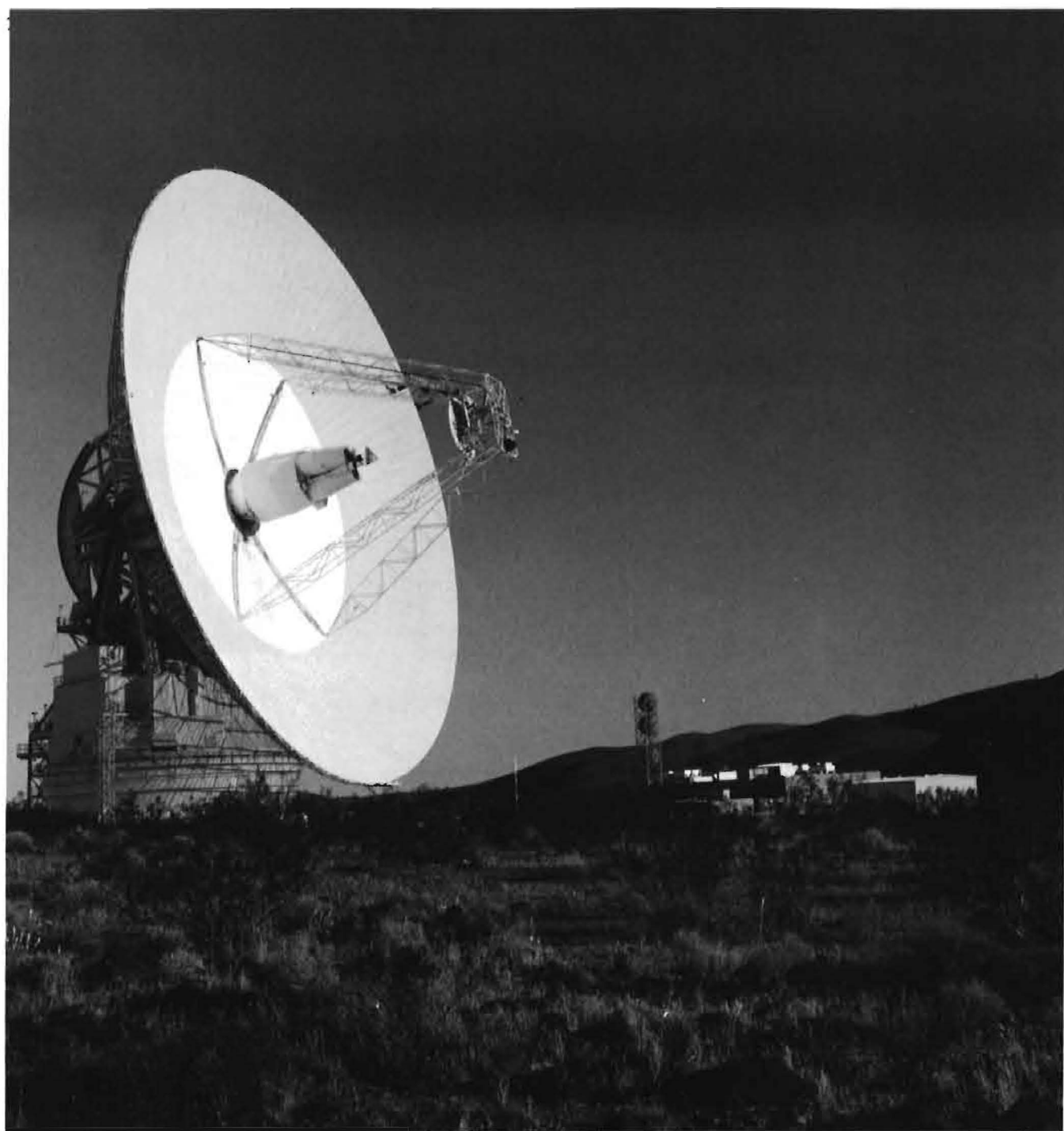
Engineers and scientists from JPL and NASA's Ames Research Center continued, throughout 1985, to develop and test prototype instrumentation and observational techniques for the NASA Search for Extraterrestrial Intelligence (SETI) program.

The goal is to detect radio signals of possible intelligent origin that originate beyond the solar system. The approach is to conduct microwave searches using advanced spectral-analysis technology with existing radio-telescopes, including DSN antennas. Full-scale observations are planned for the 1990s.

In 1985, JPL began testing an all-sky-survey approach using the Goldstone 26-meter antenna with the DSN's 65,000-channel digital fast-Fourier-transform (FFT) spectrum analyzer. The FFT has been modified to operate with variable resolutions between 1 and 300 hertz and to perform on-line processing to compress the data by a factor of 100 or more.

In March 1985, the Ames Research Center's 72,000-channel spectrum analyzer was tested at Goldstone using signals from the Pioneer 11 spacecraft.

The giant 64-meter-diameter Deep Space Network antennas, such as this one at Goldstone, California, will be used to supplement the all-sky survey of the Search for Extraterrestrial Intelligence (SETI).



MATERIALS SCIENCE

DDM

SUPERFLUID HELIUM
EXPERIMENT

ACES

3AAL

The use of space for manufacturing new materials is one of the greatest goals of the U.S. space program. In 1985, JPL's first astronaut conducted experiments in Earth orbit that should make valuable contributions to our ability to perform such work. Additional work in the field of materials science promises other advances.

DROP DYNAMICS MODULE

The JPL-developed Drop Dynamics Module (DDM) was launched into orbit on space shuttle Challenger on April 29, 1985, as part of the seven-day Spacelab 3 mission. Accompanying the experiment into orbit was Payload Specialist Dr. Taylor Wang, the DDM principal investigator and JPL's first astronaut.

The DDM uses sound waves to levitate and manipulate liquid drops in a microgravity environment. At the heart of the DDM is an acoustic chamber into which a variety of liquids can be injected in the form of droplets. These droplets can be rotated or oscillated while their behavior is observed, and they may be operated manually by the payload specialist or placed into various automatic sequence modes.



Space shuttle Mission Specialist Taylor Wang waves to well-wishers at Dryden Flight Research Facility after his flight in Spacelab 3. Other astronauts are Mission Specialists Don Lind (left) and Norman Thagard.

After working around a hardware failure, the payload specialist was able to perform most of the desired fluid-dynamics experiments. Objectives of the first flight of the DDM included observing and studying the various equilibrium shapes that free liquids can have when removed from the gravity-dominated environment of Earth-based laboratories.

In this manner it was possible to confirm the types of shapes as well as the paths connecting those shapes predicted by astronomers and fluid physicists. Drops of different liquids with a range of viscosity and surface tension were observed to all act in a similar fashion whether rotating at slow rates as oblate spheroids or at faster rates as two-lobed or dog-bone shapes. Behavior consistent with the predicted regions of instability was seen, but the point of bifurcation between the two general classes of shapes occurred at a lower rotation rate than expected.

SUPERFLUID HELIUM EXPERIMENT

The Spacelab 2 mission, an eight-day shuttle mission launched on July 29, 1985, carried the Superfluid Helium Experiment, conceived and built at JPL. The experiment is an outgrowth of the development of cryogenic systems for the Infrared Astronomical Satellite.

Helium never becomes a solid, but remains a liquid even at absolute zero. Below -455.3

degrees Fahrenheit (about 4 degrees Fahrenheit above absolute zero), helium is transformed into the superfluid state, in which it has a resistance to flow several thousand times smaller than any other liquid and conducts heat about 1,000 times better than any other material, even in films only 50 atoms thick. Because of this high thermal conductivity, temperature variations in superfluid helium are small, only a few thousandths of a degree. In addition, helium in small pores can develop a high pressure, the fountain pressure, when subjected to a small temperature difference.

The low temperature, stability, high thermal conductivity, and fountain pressure make liquid helium nearly ideal for use in space to cool certain instruments such as infrared telescopes, which must operate near absolute zero.

Because of its complex nature, superfluid helium has attracted the attention of experimental and theoretical scientists for 80 years. They are now beginning to understand the causes of its unusual properties. Superfluid helium appears to be made up of two interpenetrating fluids, one that has no resistance to flow and one that behaves normally. These fluids slip past one another with only a small amount of interaction. Their behavior can be studied by inducing waves in the fluid, which causes relative slippage. In the experiment, JPL scientists studied waves in films about 25 microinches thick, which is impossible to study on Earth because any small tilt of the surface will cause the film to drain away. Analysis of the velocity and attenuation of the waves will give further insight into the fundamental theory of superfluid helium and, hence, of all liquids.

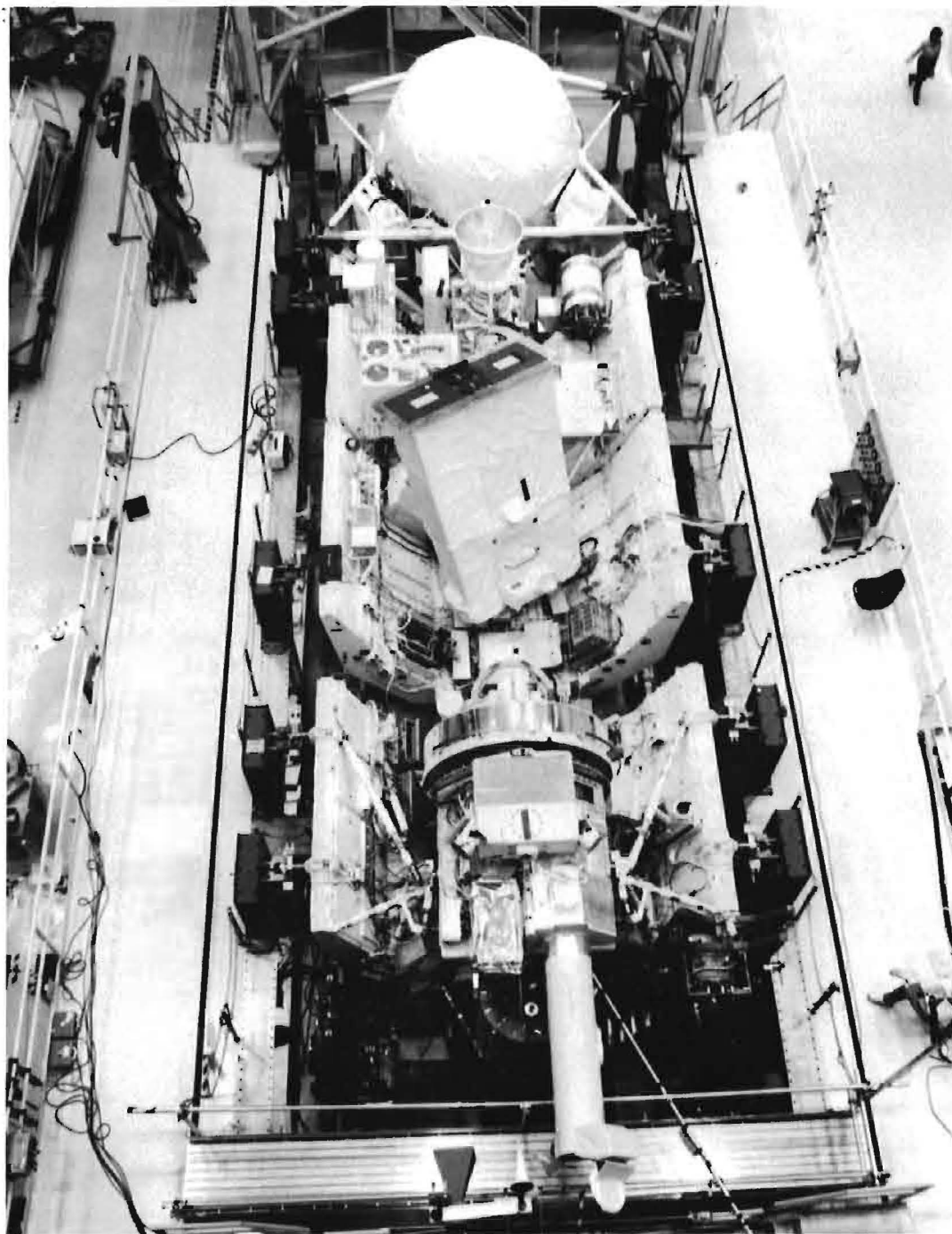
ACOUSTIC CONTAINERLESS EXPERIMENT SYSTEM

The Acoustic Containerless Experiment System (ACES) is a reflyable space shuttle middeck payload that uses three-axis acoustic levitation to support a material sample as it is melted and resolidified at high temperatures in a microgravity environment.

Containerless processing avoids introducing impurities during meltdown, always a problem whenever a crucible is used. During its initial flight in February 1984, ACES melted, manipulated, and then resolidified a sample of fluoride glass, a material that may one day be used in low-loss optical systems. In 1985, the ACES instrument underwent refurbishment and upgrading.

THREE-AXIS ACOUSTIC LEVITATOR

The Three-Axis Acoustic Levitator (3AAL) is designed to study compound fluid droplets and liquid shells that are acoustically suspended in microgravity. Fluids of differing viscosities are used in a series of investigations. The 3AAL is in many respects a miniature, automated version of the Drop Dynamics Module that flew on Spacelab 3, but it requires only a minimum crew. The 3AAL had been scheduled to go into orbit in late December 1985 as one experiment aboard the Materials Science Laboratory-2 (MSL-2), a partial payload on space shuttle Mission 61-C.



The Superfluid Helium Experiment takes its place (upper right corner of the cargo bay) with other experiments of the Spacelab 2 mission in the space shuttle.

ADVANCED
TECHNOLOGY

OPTICAL SYSTEMS

AMP

TELEROBOTICS

CCD DEVELOPMENT

ULTRAVIOLET EXCIMER
LASERS

ATMOSPHERIC WIND
SENSOR

Development and application of advanced technology is an important goal of JPL. Advanced technology is applied research leading to new methods, techniques, processes, materials, or devices.

JPL pursues advanced technology in selected fields, using discretionary resources and recruitment to exploit emerging technological opportunities. Three fields are maintained today: Optical Systems, Advanced Microelectronics Program (AMP), and Automation and Robotics (A&R) Program.



Engineers working in telerobotics test software for a new force-reflecting gripper control. The system will allow a telerobot operator to control both the position of the robot's gripper and the forces the gripper applies to an object. The gripper feeds back the position and forces to the trigger in the operator's left hand.

OPTICAL SYSTEMS

The purpose of Optical Systems is to develop new and improved optical instruments and devices for observation, remote sensing, data processing, and communication in future space missions.

ADVANCED MICRO-ELECTRONICS PROGRAM

The AMP goal is to conduct long-range applied research in computer architecture and sub-systems, optoelectronics, advanced solid-state-device concepts, and spaceborne very large scale integrated circuits (VLSI). The objective is to support JPL's missions and to make the Laboratory a center of excellence in those fields.

Highlights in 1985 include the following activities:

- ☆ Eleven new AMP research initiatives and two larger research efforts were funded through the JPL Director's Discretionary Fund.
- ☆ Plans were made to locate AMP laboratories and personnel in two new buildings: the Earth and Space Science Laboratory, under construction, and the adjacent Microdevices Laboratory, in the design phase.
- ☆ Dr. Robert Nathan of AMP received a \$20,000 NASA award for achievements in image processing, including design of a custom-integrated circuit that reduces processing time by a factor of 100.

In addition, advances in research were made in concurrent computing and submillimeter-wave detectors.

Hypercube Project

JPL continues to play a leading role in the field of concurrent computing with the Hypercube Project. Twenty-one applications have been implemented, at Caltech and at JPL, on the three 32-node and one 128-node Mark II hypercubes designed and fabricated at JPL. In 1985, three commercial firms began producing hypercubes. All three were inspired by the initial work done at Caltech, and Intel's hypercube was produced under a license from Caltech.

The next generation (Mark III) hypercube was designed at JPL and several nodes have been fabricated. Each node has the computing power of one to two VAX 11/780 minicomputers made by Digital Equipment Corporation. A 32-node Mark III prototype with the computing power of a CRAY-1 at one-tenth the cost is scheduled for completion in spring 1986. One of AMP's goals is to build a 256- to 1024-node Mark III super-computer.

Submillimeter-Wave Detectors

Submillimeter-wave astronomy is largely an unexplored field because Earth's atmosphere is opaque to submillimeter waves and because suitable detectors for that region of the spectrum do not exist. Submillimeter-wave radiation is characteristic of rotational states of small molecules, and submillimeter astronomy will provide clues to the origins of the universe.

JPL is working on a low-noise superconducting-insulating-superconducting (SIS) mixer that requires extremely low local oscillator power for heterodyne detection of submillimeter waves. JPL has succeeded in making stoichiometric niobium nitride superconductors

that will allow detection up to 1,500 gigahertz. The goal is to use all refractory, mechanically, and chemically stable materials in the SIS junction to provide the durability and reliability needed for a space mission.

AUTOMATION AND ROBOTICS PROGRAM—TELEROBOTICS

In 1985, JPL was designated as the lead center for NASA's new Telerobotics Program, which builds on the technology base developed at JPL for the Mars Rover. Areas of technology to be developed will reach from the human operator to the end effectors or hands of the robot and will include sensing and perception, task planning and reasoning, control execution, and operator interface. With these technologies, telerobots can be developed to assemble, service, and repair space structures and satellites and eventually to explore the surfaces of planets.

Sensing and Perception—Machine Vision

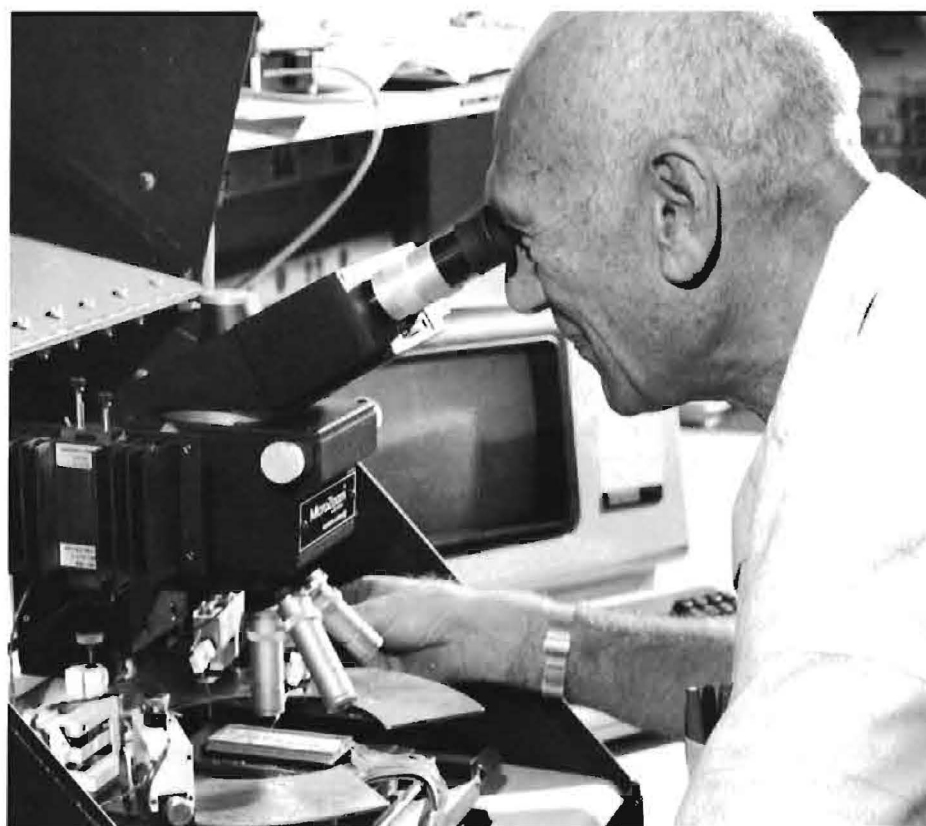
Sensing and perception provide the input data to the telerobot from the external environment. The objective is to develop a hardware/software system that can recognize, acquire, and track objects; verify task completion; and visually guide mobile platforms in free space or on planetary surfaces.

Activities in fiscal 1985 focused on Programmable Image Feature Extractor (PIFEX) development. PIFEX will be a

An engineer puts the first node of the Mark III hypercube computer through its initial testing phase. Hypercube computers promise to revolutionize computing with new power and speed at significantly lower cost than other supercomputers.



Dr. Robert Nathan (right) is at work on the image-processing project that brought him a NASA award.



real-time pipelined image-processing system that can perform 10^{11} operations per second on 12-bit data. Feasibility of the system was demonstrated by designing, fabricating, integrating, and demonstrating special VLSI chips that comprise a one-module prototype of an eventual 120-module system. The prototype demonstrated the feasibility of real-time machine vision.

Task Planning and Reasoning—Artificial Intelligence

Task planning and reasoning provide the brain of the tele-robotic system and will be the driving technology leading from teleoperated systems to robots. Continuing research in expert systems for JPL's mission operations will contribute significantly to this evolution. The JPL expert systems—PLAN-IT, DEVISER, and FAITH—all achieved significant milestones in 1985.

PLAN-IT is an expert-system schedule planner. The planning problem involves reordering and interleaving activities into a conflict-free timeline.

The core of PLAN-IT holds the knowledge needed to move or alter events, to relate individual steps to broaden activities, and to measure the level of conflicts and resource utilization. Expert strategies overlay the core and allow PLAN-IT to develop schedules resolving conflicts in a manner that mimics the expert who provided the knowledge. Early evaluation of PLAN-IT has shown that even simplistic strategies can result in remarkably good plans with a very favorable response time.

DEVISER, a knowledge-based planner for configuration planning, was demonstrated on Voyager sequencing in the first quarter of 1985. The off-line

demonstration covered the near- and post-encounter phases of the Uranus encounter.

During the near-encounter planning demonstration, DEVISER satisfied most of the observation requests in 2.5 hours. Human sequence generation and integration to the same level of accuracy would have required between one and two workweeks of effort. The demonstration proved the feasibility of configuration planning with expert systems.

In 1985, the FAITH error diagnoser was expanded from a very small feasibility study to a real-time operation tested on the Voyager 2 photopolarimeter sensor. Capabilities include simulation of system components, manipulation of basic assumptions during reasoning, and generation of some natural-language explanation for its reasoning processes. Performance enhancements halved execution time for typical problems in FAITH.

Control Execution—Interactive Automation

Systems must be developed that allow the real-time control of space telerobots in alternative manual and automatic modes of operation. Telerobotics will require the use of mechanical hands equipped with a multitude of sensors. That, in turn, will require the integration of significant data-handling and computing power into the mechanical hand. To study, demonstrate, and evaluate the implications of local computing in a mechanical hand, a smart hand mechanism was designed and fabricated for a robot arm.

The novelty and payoff of this software development is the full electronic and computational (not mechanical) implementation of force-reflecting, manual control of a remote

robot arm using a general-purpose, back-drivable, manual control device.

Operator Interface

Human operators face a special problem when working with teleoperators in the environment of space. Because of the time required for signal transmission and processing, there is a time delay between the movement input by the operator and the visual and force feedback from the teleoperator. To work around the problem, JPL developed a computer-predictive display to overlay the real picture of a robot arm. This display anticipates the actual location of the arm while waiting for the processed information. The predictive display is being used to evaluate control strategies in telerobot control with a communication time delay.

CHARGE-COUPLED DEVICE DEVELOPMENT

Until recently the usefulness of the charge-coupled device (CCD) as an imaging sensor was restricted to within rather narrow boundaries of the visible and near-infrared spectrum. Intensive JPL studies and experimentation, however, have shown that the CCD can be made to directly respond with high sensitivity in the ultraviolet (UV), extreme ultraviolet (EUV), and soft X-ray regions, covering more than four magnitudes (1 to 11,000 angstroms) of the electromagnetic spectrum. The principal factor responsible for the increased spectral coverage was the technique discovered in 1985 that reduces the surface dead layer of the CCD to

less than 50 angstroms and simultaneously creates a high electric-field condition at the surface that directs photoelectrons to the CCD potential wells. The findings have prompted a number of new proposals for using the CCD to detect radiation outside the visible spectrum. Many of the applications are being directed toward new flight projects such as the Comet Rendezvous Asteroid Flyby, the Solar Optical Telescope, and the decade imaging spectrograph and camera and visible- and near-infrared camera, two instruments destined for future flight aboard the Hubble Space Telescope.

ULTRAVIOLET EXCIMER LASERS

The excimer laser technology developed at JPL was used in 1985 to address significant problems.

Considerable national concern exists about the effects of released chlorofluorocarbons reaching the stratosphere and depleting the atmosphere's ozone layer, which shields the Earth's surface from harmful ultraviolet radiation. As a result, NASA chose the ultraviolet excimer laser to monitor ozone concentrations in the stratosphere. This ground-based, remote sensing system is being established at the Table Mountain Observatory to provide NASA with precise data on possible long-term variations in the stratospheric ozone layer.

In addition, the JPL excimer laser, coupled with a flexible, thin, fiberoptic delivery system,

has shown promise for reopening clogged coronary arteries. This is a significant transfer of excimer laser technology to a biomedical application.

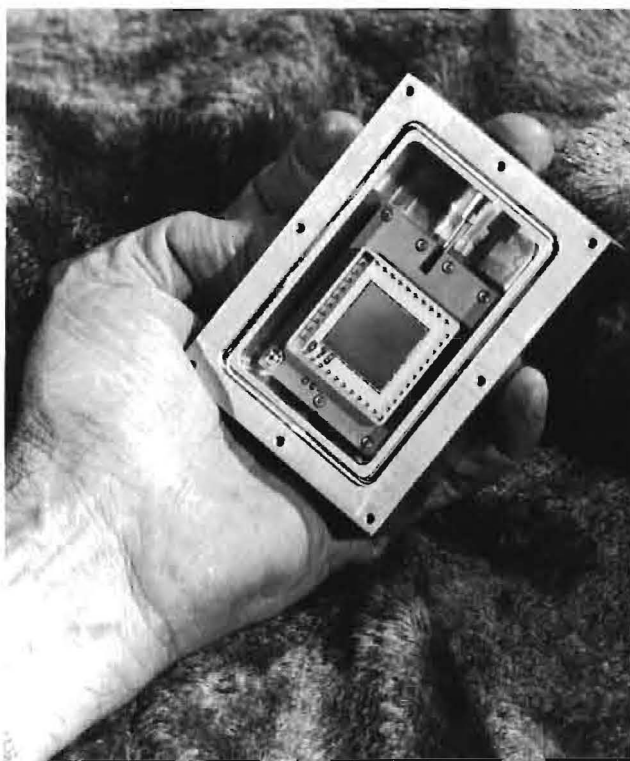
The excimer laser angioplasty procedure may be used as an alternative to heart-bypass surgery. The short-pulsed, ultraviolet excimer laser radiation was shown to vaporize atherosclerotic plaque without causing thermal damage to remaining tissue. Earlier attempts to use other types of lasers for the procedure were unsuccessful because plaque ablation could not be adequately controlled and there was extensive thermal damage to the wall of the blood vessel.

The biomedical work was performed in collaboration with the Department of Cardiology at Cedars-Sinai Medical Center in Los Angeles.

ADVANCED DEVELOPMENT OF AN ATMOSPHERIC WIND SENSOR

A satellite-borne sensor that will measure winds in the upper atmosphere is being developed at JPL. The sensor measures wind-induced Doppler shifts in the naturally occurring infrared thermal emission of gases in the stratosphere and mesosphere.

The observational approach employs gas correlation spectroscopy, a measurement technique that has been used to remotely sense temperatures and concentrations of trace gaseous constituents in the upper atmosphere. Wind is a major factor in determining global distribution of many trace atmospheric species, including ozone. Yet wind velocities in the upper atmosphere have never been measured globally.



A 1024-by-1024-element virtual-phase charge-coupled device (CCD) is being developed by JPL and Texas Instruments. The CCD will be used in cameras for future planetary missions.

DEFENSE AND CIVIL PROGRAMS

ASAS/ENSCE PROJECT

ASSET

UNMANNED ROBOTIC
LAND VEHICLES

CONTENT-ADDRESSABLE
MEMORIES

ACQUISITION, TRACKING,
& POINTING PROJECT

SP-100 PROJECT

FSA PROJECT

ENERGY CONSERVATION

ENERGY SYSTEMS
TECHNOLOGY

COMMUNICATION
NETWORK

In 1985, the Laboratory consolidated its defense work (begun in 1981) and its civil efforts (that date back to the 1960s) into Defense and Civil Programs. Therefore, virtually all non-NASA work is managed within one program office with a single, common approach to management, work selection, and resource allocation.

The goal of Defense and Civil Programs is to seek projects and technologies that complement the Laboratory's traditional NASA responsibilities yet add to JPL's vitality.



Soldiers on field maneuvers work with equipment of the ASAS/ENSCE project, a baseline data-processing system to fulfill U.S. Army and Air Force tactical intelligence needs of the early 1990s.

ASAS/ENSCE PROJECT

Development of the All Source Analysis System/Enemy Situation Correlation Element (ASAS/ENSCE) project continued in 1985. Its mission is to field a baseline data-processing system to fulfill U.S. Army and Air Force tactical intelligence needs in the early 1990s.

ASAS/ENSCE will use computer workstations in mobile field modules. These modules will receive large quantities of intelligence data, analyze and prioritize it, then automatically process the data and display it for battlefield commanders.

JPL conducted project-definition and systems-architecture engineering, and is performing systems-software development. Work is going forward on design, manufacturing, hardware, and applications-software acquisition, on software integration, testing, and training, and in field support.

JPL will also incorporate improved message-handling capabilities and ensure, through product-improvement, that the system design and architecture will incorporate future software and hardware improvements.

Plans call for deployment of an early capability for the Army's light divisions. The early deliveries, to be transported on 1 1/4-ton trucks, consist of elements of a complete system. A brassboard version of an ASAS Interface Module was tested during the Border Star exercise at Fort Bliss, Texas, in early 1985 and at the Cascade Peak exercise at Fort Lewis, Washington, in November.

Meanwhile, in 1985 JPL continued work on a number of other tasks, covering a wide range of technical disciplines, for the Army.

UNMANNED AERIAL VEHICLE SYSTEMS

The Airborne Surveillance Sensor Evaluation Test-bed (ASSET) system comprises visual sensors on a small, piloted aircraft. The sensors are controlled from and displayed in a mobile shelter up to 100 kilometers away. Thus, real-time scenes of the battlefield, both day and night, are evaluated by image interpreters. Surveillance reports are then relayed to the battlefield commander. The system is designed to be operated by Army personnel in force-on-force exercises to evaluate advanced sensors and operational and organizational concepts for gathering intelligence from a distant aircraft.

Several improvements were made to the sensor packages and ground-processing equipment in 1985. Improvements included stabilization of the infrared sensor and television payloads and evaluation of a new, high-resolution color-television camera. On the ground, a freeze-frame and image-enhancement capability was added so that image interpreters could make more accurate and timely reports using a new digital message system. ASSET was used in three separate field exercises during 1985, supported by JPL personnel. The Army lent the system and its remotely piloted vehicle (RPV) platoon to the Marine Corps for two exercises in which a radio-relay payload was also flown. Intelligence data were transmitted from the Ground Control Station to an offshore Naval command vessel.

Because there is a need to conduct surveillance when clouds, dust, or fog obscures the view, JPL has been developing a passive millimeter-

wave (MMW) sensor for ASSET. Initial flight tests used a helicopter to seek out fog and other weather-related test conditions and yielded satisfying results. The MMW imager will be integrated with ASSET for more evaluation.

The tactical value of an unmanned aerial vehicle (UAV) is not limited to imagery intelligence alone. Additional uses, such as signals intelligence, electronic warfare, and chemical detection, were investigated. Using experience gained in ASSET, JPL developed system concepts and functional designs for each candidate. A multiyear payload-integration plan was produced for the Army to evaluate according to tactical priority, status of the technology, availability, and cost.

JPL continues to support the Army's Aquila remotely piloted vehicle program as it concludes the engineering-development phase. Efforts have involved technical and program planning, reviews, and assessments in specialized areas including software development, flight controls, and mission payloads.

UNMANNED ROBOTIC LAND VEHICLES

JPL actively participated in the Army's program to develop technology for controlling and navigating unmanned land vehicles. The Army's primary interests are applications in hazardous operations and in increased efficiency and effectiveness of soldiers in combat and combat support. The



At the conclusion of a flight, technicians capture the Army Aquila remotely piloted vehicle in a net. Aquila is captured in this fashion instead of landing because the aircraft does not have a landing gear. Aquila's development is complete, and the Army is preparing for production of the unmanned artillery-spotting aircraft. (Lockheed Missiles & Space Company, Inc.)

problem of remotely piloting and safely navigating unmanned vehicles parallels NASA's work on planetary rovers. The work thus forms a basis for expanding robotic control and navigation technology.

A prominent problem is robotic navigation—planning a safe and efficient route to a desired destination. In 1985, JPL completed research that exploits state-of-the-art symbol-processing techniques to automate route planning. The approach uses a digital terrain data base so a computer can generate a map and then automate portions of the navigation planning function.

Other efforts focus on automating the local piloting functions of the vehicle. The technique is based on stereo machine-vision technology developed by NASA to provide unmanned, autonomous mobility from remote sites. Work done in 1985 validated the concept, and an integrated demonstration in the nearby Arroyo Seco is scheduled for spring 1986.

CONTENT-ADDRESSABLE MEMORIES

JPL is investigating a promising approach to ultra-high-density information storage for future computers. The approach is based on a neural-network model derived from concepts of information storage and retrieval hypothesized for the human brain. The network forms the basis for a content-addressable memory with parallel input-output capability. The network also exhibits a built-in capability to perform logical functions such as pattern recognition, subject classification, and error correction that permits new approaches to more complex machine intelligence.

During 1985, work demonstrated the dynamic behavior of neural-network memories with a 32-by-32 programmable binary switch matrix in hardware form using discrete components. The characteristics of binary square matrices of sizes up to 256 by 256 were investigated.

ACQUISITION, TRACKING, AND POINTING PROJECT

JPL continues to support the nation's defense in ongoing space activities. A project involving acquisition, tracking, and pointing space experiments is under way for the Strategic Defense Initiative Office/Directed Energy Office. The work emphasizes technologies associated with precise tracking.

The work at JPL is closely tied to research by the Air Force Space Division and the Naval Research Laboratory; the objective is to plan and implement space experiments that can guide ongoing pointing and tracking technology.

JPL has the primary responsibility for program planning and implementation of specific experiments. During 1985 definition phases were completed for two potential shuttle-based experiments. One involves gathering booster-plume data and the other involves demonstrating precision tracking of a ground-target site by reflection of a low-power laser beam. Implementation of one experiment is expected in 1986.

SPACE REACTOR POWER SYSTEM

In 1985, the Laboratory completed Phase 1 of the Space Reactor Power System (SP-100), a project to develop multihundred-kilowatt-class (20 to 1,000 kilowatts electric) power-system technology so that space mission planners and users may use it in the mid-1990s and beyond.

Phase 1 identified users and applications and determined functional requirements. System concepts were also defined. Technical issues associated with those concepts that determine technical feasibility were defined and solutions were examined. Of the wide range of concepts that were examined, three were selected: in-core thermionics, thermoelectrics, and Stirling. Phase 1 was completed with selection of thermoelectrics.

Phase 2, the Ground Engineering System (GES), began in 1985. The GES will use work done in Phase 1 on thermoelectric technology.

In 1985, a Request for Proposal was issued for a system contractor to perform work on major subsystems.

FLAT-PLATE SOLAR ARRAY PROJECT

During 1985 the Laboratory reduced much of its work on the Flat-Plate Solar Array (FSA) project, whose goal has been to develop technologies that will lead to economical generation of large quantities of electricity from photovoltaic panels. Through in-house work and subcontracts with universities, other laboratories, and industry, the project has helped define a clear-cut path to that goal.

Broad advances in all aspects of flat-plate photovoltaic technology have been made by the project and the photovoltaic industry: Production of large-scale, low-cost polycrystalline material is forthcoming, commercial production of high-quality photovoltaic modules is in progress at various companies, advanced shaped-sheet module technology is nearing the prototype stage, and deployment of utility-scale systems is increasing. The project expects to complete all contractual work by September 1986.

ENERGY CONSERVATION

The U.S. Department of Energy is sponsoring work to demonstrate the corrosion resistance of sputter-deposited amorphous metallic coatings on alloys that are exposed to acid dew-point conditions in heat-recovery systems.

Some of the combustion products of sulfur-laden fuels such as coal combine to produce sulfuric acid when the exhaust-gas temperature falls below the acid dew point (175 degrees Celsius). Heat extraction below that temperature rapidly corrodes steel heat exchangers. Super alloys and stainless steel are more corrosion resistant, but their higher costs offset the savings in fuel costs by recycling the low-temperature heat. A potentially lower cost alternative is to coat the steel with a thin layer of corrosion-resistant material.

Many liquid-quenched amorphous metallic alloys (i.e., metglas) have superior corrosion resistance, but they are

produced as powder or ribbon not applicable for coatings. Vapor-quenched amorphous films, however, can be deposited with magnetron sputtering techniques. The JPL study is measuring the corrosion resistance of vapor-quenched films to determine the feasibility of depositing thick films (1 mil or greater) on steel of various shapes (tubes or fins, for example) and to evaluate the corrosion characteristics of the coated steel in an acid dew-point environment. The basic technology could be used in many corrosion applications and would help conserve strategic materials such as chromium.

Accomplishments in 1985 include

- ☆ Vapor-quenched materials were determined to have equal or better corrosion resistance than liquid-quenched materials.
- ☆ Films up to 2 mils thick were deposited on steel.
- ☆ An alloy composed of iron, chromium, phosphorus, and carbon was immersed in sulfuric acid at room temperature and was shown to be two to three orders of magnitude more corrosion resistant than 304 stainless steel.

ENERGY SYSTEMS TECHNOLOGY

JPL is supporting development of an advanced electric-power vehicle for the Electric Power Research Institute (EPRI). The goal of the program is to demonstrate an electric van for commercial use by the early 1990s. JPL's contribution is to develop an AC drive train. The work consists of devising a new concept for a high-performance, sealed, lead-acid battery, the thermal-management system, DC/AC inversion, controls, and a charger/state-of-charge indicator.

COMMUNICATION NETWORK VULNERABILITY

A recent planning study, which examined civil sector areas where JPL capability could be effectively applied, identified the vulnerability of national networks as an area of increasing concern.

Federal and civil crisis-communications systems are vulnerable to man-made and natural disasters. These systems do not generally provide for networking among the various agencies involved.

A crisis communications operational concept and network design, based on the commercial Mobile Satellite System expected to be operating by the early 1990s, is being developed by JPL for the National Communications System, a federal agency.

Initial work on the task involves a scenario of an 8.3-magnitude earthquake in the San Bernardino County, California, area. Federal, state, and local agencies that would be involved in such an emergency are cooperating.

TELECOMMUNICATIONS SYSTEMS

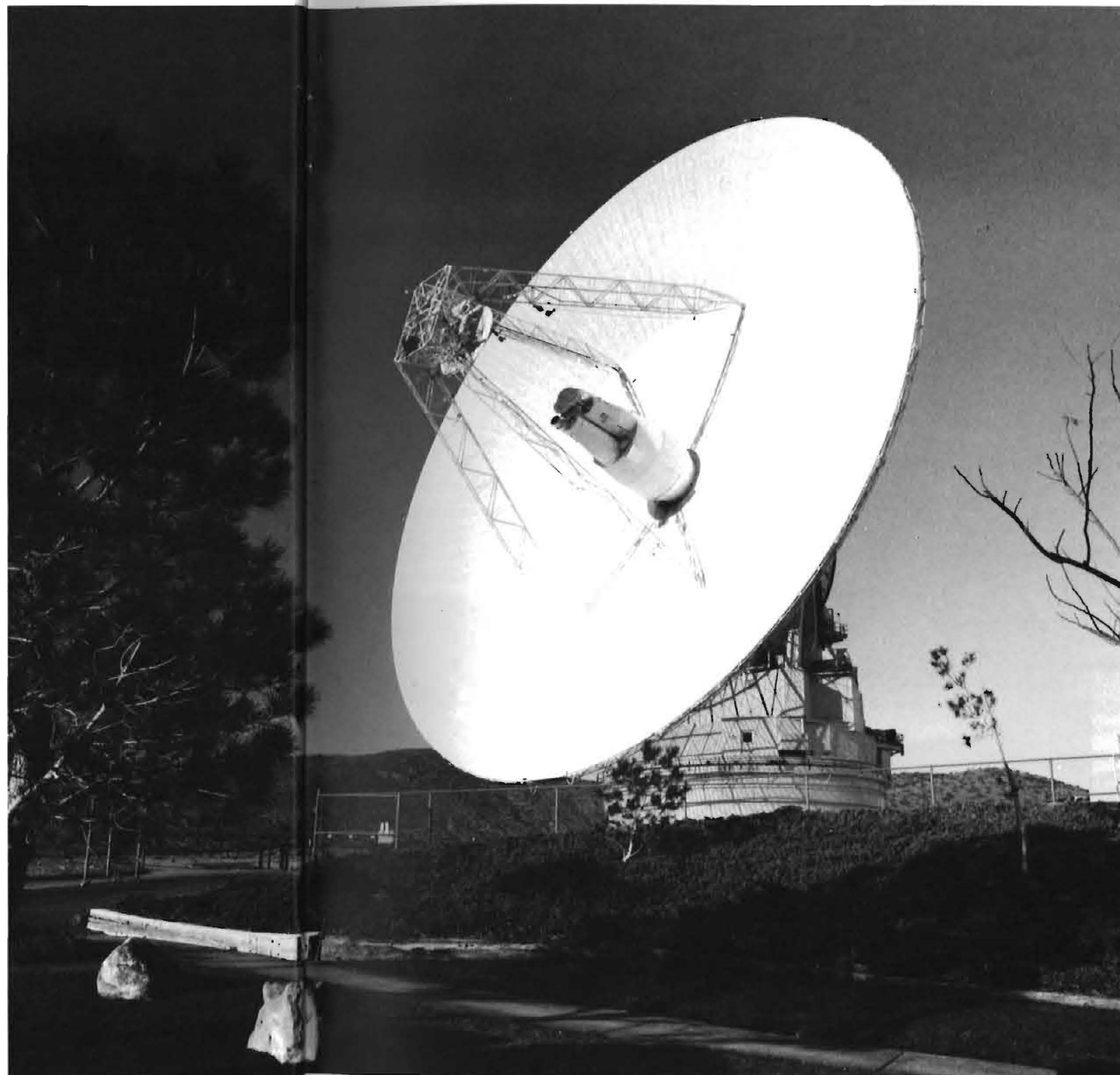
MISSION SUPPORT

FUTURE MISSION
SUPPORT

TECHNOLOGY DEVELOPMENT

The Deep Space Network (DSN) is NASA's worldwide system for communicating with spacecraft exploring the solar system. The network, managed by JPL, consists of antennas that transmit instructions from Earth to the spacecraft and that receive the data the spacecraft has gathered and returned from deep space.

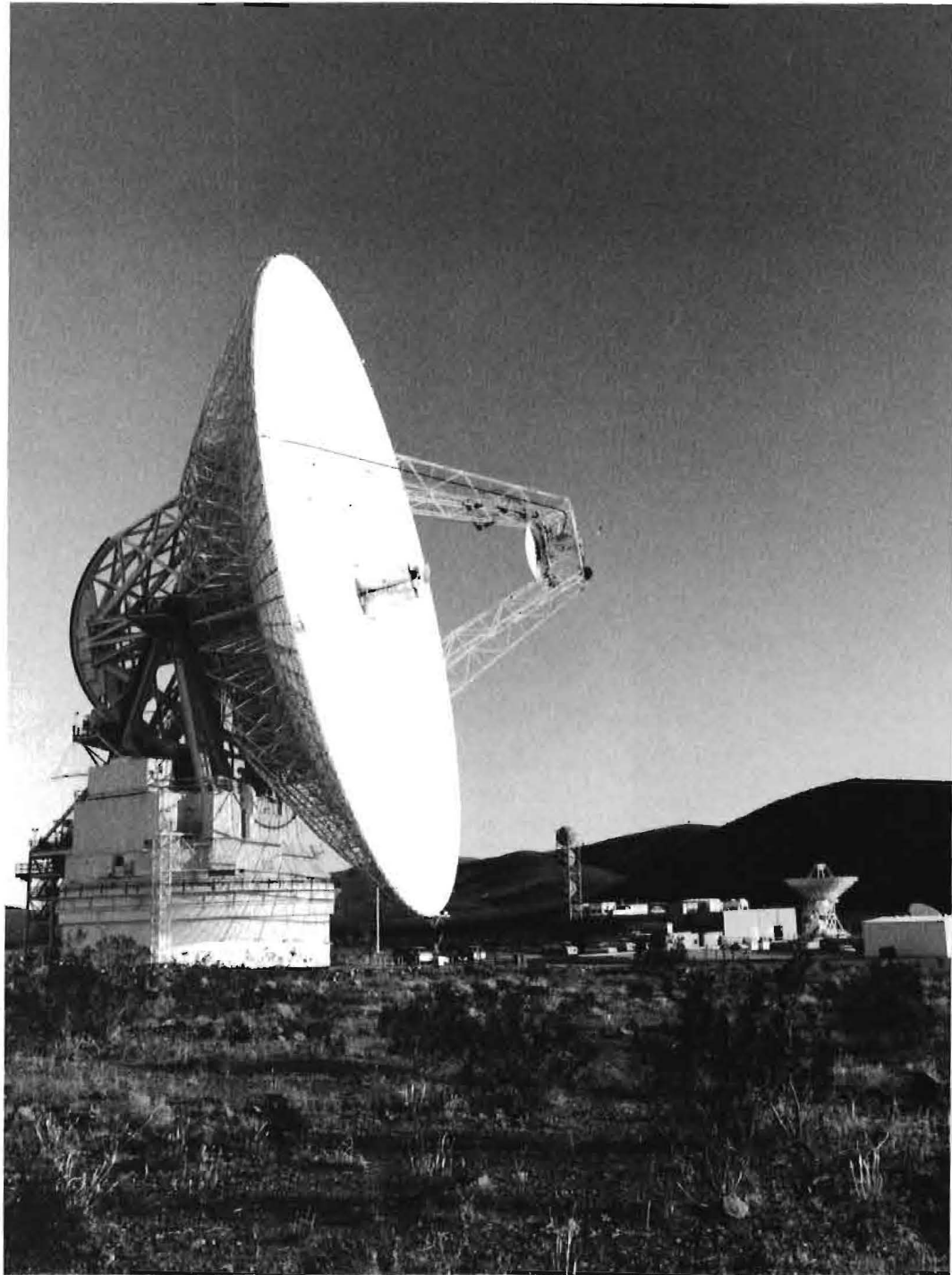
The DSN was established in 1958 to support the first U.S. satellite, Explorer 1. Since then the network has grown to include 11 antenna systems (with a 12th under construction), a Network Operations Control Center and ground facilities at JPL, and ground communications that link all locations. The antennas are clustered at Deep Space Communications Complexes near Goldstone in California's Mojave Desert; Madrid, Spain; and Canberra, Australia. These widely separated locations (approximately 120 degrees of longitude apart) ensure that spacecraft traveling beyond the rotating Earth are almost never out of view.



The Deep Space Network's 64-meter-diameter antenna at Goldstone, California, supported a variety of space-flight projects, including Voyager 2's encounter with Uranus, the ICE encounter with Comet Giacobini-Zinner, and the international Venus Balloon experiment.

The Deep Space

Network is currently undergoing an expansion phase. One result will be to increase this antenna at Goldstone from 64 to 70 meters in diameter.



Each complex is equipped with a 64-meter-diameter antenna station, which will soon be improved in efficiency and expanded to 70 meters in diameter. The smaller antennas at each complex—26 and 34 meters—are being joined by new 34-meter, high-efficiency antennas in anticipation of the greater communications challenges that lie ahead.

The complexes can also be teamed for scientific investigations with such techniques as Very Long Baseline Interferometry (VLBI), in which measurements made by two or more widely spaced antennas are combined. Such arraying allows the antennas to obtain the same resolving power as a single, giant antenna spanning the distance between them. The VLBI technique is used both for navigating distant spacecraft and for making precise geodetic measurements.

Communication with spacecraft in deep space will always be its primary focus, but the DSN has also assumed responsibility for all Earth-orbiting satellites that are not compatible with NASA's new Tracking and Data Relay Satellite System (TDRSS). In addition, the DSN will provide launch transfer-orbit support to a variety of spacecraft bound for geosynchronous orbit, and emergency support for the tracking satellites themselves and for other spacecraft that would normally communicate through TDRSS.

MISSION SUPPORT

Operations

In 1985, the DSN supported the following flight missions:

- ☆ The Pioneer missions, operated by NASA's Ames Research Center. Pioneers 10 and 11 continued to return scientific data from previously unexplored regions of the outer solar system. Pioneer 12—the Venus Orbiter—continued to provide data on the Venusian atmosphere and will observe Comet Halley in early 1986. In 1985 Pioneer 6—the world's oldest functioning spacecraft—exceeded 20 years of operation by continuing to return solar weather data from its orbit.
- ☆ The Active Magnetospheric Particle Tracer Explorers (AMPTE), which, in December 1984 and July 1985, released canisters of barium and lithium particles to study the interaction of Earth's magnetosphere with the solar wind.
- ☆ The International Cometary Explorer (ICE), as it passed through the tail of Comet Giacobini-Zinner on September 11, 1985. Arrangements were made with the Usuda Deep Space Station of Japan's Institute of Space and Astronautic Sciences and with Cornell University's Arecibo Observatory in Puerto Rico to help support ICE during the comet encounter period. The DSN and the Usuda station continued to support ICE during its October 1985 radial alignment with Comet Halley and Earth, and the DSN will

support ICE throughout its second radial alignment in March 1986.

- ☆ Voyagers 1 and 2. The major emphasis was on Voyager 2 as it approached Uranus.
- ☆ The international Venus Balloon and Pathfinder missions. The missions use the two Soviet "Vega" spacecraft, named for Venus and Galley (the Soviet name for Halley's Comet). The DSN will provide VLBI-derived navigation support for the Vegas near Halley and provide improved navigation to the European Giotto mission.
- ☆ The European Space Agency's (ESA) Giotto spacecraft during launch on July 2, 1985; support will continue through its Comet Halley encounter in March.
- ☆ Sakigake (MS-T5) and Suesei (Planet A), which are Japanese spacecraft studying Comet Halley.

Mark IVA Implementation

In 1985, the DSN completed its Mark IVA Implementation Project, a five-year task designed to centralize control of network subsystems and to increase operational support capabilities.

At each complex, a Signal Processing Center enables centralized monitoring and control and permits unattended operation of remote and antenna-mounted assemblies. This center, which includes new

data processors for several sub-systems, connects all sub-systems through a serial Local Area Network (LAN). All antennas (one 64-meter, two 34-meter, and one 26-meter) and associated equipment at a complex are now controlled and monitored through the Signal Processing Center.

The Mark IVA implementation for the Goldstone complex was completed when Goldstone became operational in April 1985. Next on line was the Australian complex in July. The project came to a close when service was returned to the communications complex at Madrid in August.

Networks Consolidation Program

The Networks Consolidation Program was completed in February 1985 with consolidation into the DSN of a reconfigured three-station, 26-meter-antenna subnet for support of selected Earth orbiters.

The three 26-meter stations were originally part of the Goddard Spaceflight Tracking and Data Network (GSTDN). Two overseas stations (Canberra and Madrid) were relocated near the sites of the DSN Signal Processing Centers in their respective countries. Relocation included disassembly and re-erection of the 26-meter X-Y antenna structures and allowed them to be collocated with the existing Deep Space Communications Complexes at Canberra and Madrid. Management of the new subnet was transferred from Goddard Space Flight Center to JPL on February 1.

With the addition of the 26-meter-antenna subnet capabilities, the DSN assumed responsibility for support of existing NASA Earth-orbiting missions that are not compatible with the Tracking and Data Relay Satellite System (TDRSS).

Mission support with the 26-meter antenna subnet in 1985 included the International Sun-Earth Explorers 1 and 2 (ISEE 1 and 2), Nimbus 7, Dynamics Explorer 1 (DE-1), Active Magnetospheric Particle Tracer Explorers (AMPTE), and Space Transportation System (STS).

Arraying for Voyager

The Voyager 2 encounters with Uranus in 1986 and Neptune in 1989 present a serious challenge in deep-space communications. During the Neptune encounter, for example, Voyager 2's X-band radio signal will be less than one-tenth as strong as it was at Jupiter in 1979 and less than one-half as strong as it was at Uranus in 1986. Improvements to the DSN complemented improvements in Voyager 2's flight-data system program and significantly increased the potential data return. During the encounters, all DSN antennas at each longitude were arrayed. Voyager 2's signals were added together to significantly increase the potential for data return.

For Uranus, the new 34-meter high-efficiency antennas at Goldstone and Canberra increased the potential data return by 25 percent. The Parkes Radio Telescope in Australia joined with the DSN to create an additional 50-percent increase. In 1985, those arrays were successfully tested and demonstrated in preparation for the Uranus encounter.

For the Neptune encounter, the DSN is installing a third 34-meter, high-efficiency antenna in Madrid and will upgrade the network's three 64-meter antennas by improving their reflector shaping and expanding them to 70 meters in diameter. The improvements will effect a better than 50-percent increase in signal capture. During the Neptune encounter, the DSN will be joined again by the Parkes Radio Telescope and by the National Radio Astronomy Observatory's Very Large Array near Socorro, New Mexico, where the first two of the required 28 new receiving assemblies have been installed and tested.

FUTURE MISSION SUPPORT

The DSN is preparing to support the following NASA and international missions still in development or planning stages:

- ☆ Galileo: The DSN Compatibility Test Area at JPL and Cape Kennedy (MIL 71) supported Galileo test and integration activities throughout 1985. Continued testing and launch will be supported at MIL 71.
- ☆ The international Ulysses mission (NASA and the European Space Agency): DSN compatibility testing was completed during 1985 and prelaunch preparations were under way at Kennedy Space Center.



A controller in JPL's Network Operations Control Center (NOCC) works with equipment operators at DSN stations around the world. Commands to the spacecraft and scientific and engineering data from the spacecraft pass through the NOCC. Controllers here also work with personnel in the Mission Control and Computing Center, where data from the spacecraft are received.

☆ *Magellan*: This mission will require the DSN to receive and process data at the highest telemetry rate of any deep-space mission to date (268.8 kilobits per second). *Magellan* will also be the first project to use a new navigational data type called narrowband differential Very Long Baseline Interferometry (delta VLBI). This Doppler-equivalent data type is analogous to the wide-band delta-VLBI data type being used on the *Voyager* *Uranus* and *Neptune* mission and will also be used for *Galileo* support.

TECHNOLOGY DEVELOPMENT

VLBI Observations of *Uranus*

Very Long Baseline Interferometry (VLBI) locates the angular position of spacecraft in a reference frame established by observations of compact extragalactic radio objects. In order to navigate spacecraft with VLBI, the positions of the planets in the radio frame must be known. While VLBI measurements can determine the angular positions of spacecraft in the radio frame with very high accuracy, the positions of planets in that frame are not so well known.

In particular, the error for *Uranus* corresponded to approximately 5,800 kilometers of target uncertainty before the latest (1985) ephemeris—the ephemeris that was required to put the final touches to encounter planning and the initial trajectory to *Neptune*. *Uranus* was observed in April 1985, using the Very Large Array (VLA) of the National Radio Astronomy Observatory to locate the planet's position in the radio frame. The VLA observations provided independent confirmation that the accuracy of the new ephemeris was a factor of six better than the old one and represented a reduction of the target uncertainty to 1,000 kilometers, or roughly 4 percent of *Uranus*' diameter.

Coding for Communications

DSN researchers achieved a major advance in coding for deep-space telemetry. Such coding adds structure to long blocks of data to provide increased detectability in the presence of noise on the deep-space channel. Increasingly sophisticated coding/decoding schemes have been applied in JPL missions since the 1960s. The baseline configuration used on *Voyager* for the *Uranus* and *Neptune* encounters has a regular convolutional code (constraint length 7, rate 1/2) combined with an 8-bit Reed-Solomon code.

The performance of a communication system can be improved by increasing the

complexity of the coding scheme. With that in mind, the researchers undertook a selective search through potentially good codes. Three new convolutional codes were found (constraint length 14 or 15, rate 1/5 or 1/6) that combined with a 10-bit Reed-Solomon code to achieve the desired performance with a signal-to-noise ratio of only 62 percent of that needed for the baseline coding scheme. That improvement in performance is achieved at a cost of increased decoder complexity of two orders of magnitude. Even that significant increase in decoder complexity can be accommodated with today's microelectronics.

Recent progress in concurrent computing architectures has made multiprocessor systems a desirable solution for the highly complex decoding of convolutional codes. An efficient concurrent formulation of the convolutional decoding algorithm in a form suitable for the hypercube architecture has been developed, programmed, and successfully demonstrated on a 64-node hypercube. The modular and expandable structure of the concurrent decoding algorithm is expected to enable implementation of decoders with ever-increasing complexity.

New Low-Noise Amplifier

The microwave noise performance of the high electron mobility transistor (HEMT), a novel and recently developed transistor, exceeds that of the best field effect transistors (FETs) at room and cryogenic temperatures. Recent measurements indicate that when HEMTs are cooled to 12 kelvins, about 10 degrees below the boiling point of hydrogen, the noise performance will be comparable to a maser amplifier for the 1- to 5-gigahertz range, but at much lower cost.

The DSN uses maser amplifiers, custom made by JPL, in its Earth-based receiving systems. Masers are the most sensitive microwave amplifiers known, but require operating temperatures of about 4 kelvins, approximately the boiling point of helium. Development of HEMT amplifiers could allow replacement of many existing maser systems for one-quarter of the implementation cost and one-third of the operating cost.

Progress with the use of the HEMT as a microwave amplifier has resulted from a joint effort involving JPL, the National Radio Astronomy Observatory, and the General Electric Company.

Laser Communication Devices

JPL has been evaluating the use of space-based optical communication links for outer-planetary or interstellar missions

in the late 1990s. A key element in such optical communication links is the availability of high-brightness, single-mode laser emitters.

Today's semiconductor lasers can produce adequate power, but their beam quality is poor. An alternative method is to use a number of semiconductor lasers that focus on another medium, such as neodymium-doped yttrium aluminum garnet (Nd:YAG). That, in turn, lases efficiently and with a single high-quality output beam. Researchers at JPL have achieved 85 milliwatts of optical power at 8½-percent overall electrical efficiency, an order of magnitude improvement over preexisting state of the art. Work is under way to scale the device to an output power of 1 watt with anticipated efficiencies of up to 10 percent.

Symbol-Stream Combining for ICE and Voyager

On September 11, 1985, at the time of the encounter of the International Cometary Explorer (ICE) with Comet Giacobini-Zinner, the spacecraft was visible to DSN stations in both California and Spain. Although either location could support ICE under ordinary conditions, there was great uncertainty about the effects of the comet environment on the spacecraft, including the potential for severe degradation to the telemetry link. To provide enhanced telemetry performance, a non-real-time method of combining the symbol streams from the two locations was devised. Overall performance of the combined streams

is double that of either location alone, and thus provides assurance that the telemetry link could remain viable despite significant degradation.

The first step in non-real-time symbol-stream combining was to record noisy telemetry symbols received at each DSN location onto standard computer magnetic tapes. The tapes were shipped to JPL where the data were combined by a computer and decoded. During the four days surrounding the Giacobini-Zinner encounter, the received telemetry streams were recorded during all common view periods for supporting stations, to be combined and decoded as needed. Although it did not in retrospect appear essential, combining was completed for the encounter period, and for several other intervals as a demonstration of the capability. The theory was fully verified. A higher rate near-real-time system was developed for demonstration during the encounter of Voyager at Uranus. For Voyager, symbol combining was done in specially designed hardware, at approximately the same rate as the symbol recording. The combined symbols were then decoded on the standard decoders of the DSN.

**INSTITUTIONAL
ACTIVITIES**

- DIRECTOR'S DISCRETIONARY
FUND**
- PRESIDENT'S FUND**
- NASA HONOR AWARDS**
- PATENTS & TECHNOLOGY
UTILIZATION**

Research and development costs for the fiscal year ending in September 1985 were \$650 million, a 28.5 percent increase from fiscal 1984.

Costs for NASA-funded activities rose 26.3 percent to \$470 million. Civil programs costs declined to \$35 million, down 8.5 percent from the previous year, while tasks for the Department of Defense amounted to \$132 million, an increase of 55.2 percent.

The JPL work force increased slightly during the year to 5,247. Employment during the two previous years was 5,142 (1984) and 4,907 (1983).

Procurement obligations during fiscal 1985 totaled \$388 million, a 21-percent increase from the previous year. The total included \$358 million to business firms. Of that, obligations amounted to \$124 million to small business and \$11.3 million to minority business.

For Facilities, construction started in May 1985 on the 170,000-square-foot Central Engineering Building project financed by Caltech. The building is scheduled for occupancy in mid-1986. Work also started on the 99,000-square-foot Earth and Space Science Laboratory in September 1985.



Completion is scheduled for November 1986. The two major projects are initial key elements in the JPL Long-Range Facility Plan.

DIRECTOR'S DISCRETIONARY FUND

In 1985 the Director's Discretionary Fund (DDF) initiated 36 new tasks, selected from nearly 100 proposals. Particular areas of technology emphasis included advanced microelectronics, autonomous systems, applications of concurrent computing, and remote-sensor technology.

DDF funding continues to provide the major resource at JPL for support of promising innovative and seed efforts for which conventional funding is not available. In recognition of the unique importance of the resource, NASA increased the funding level in 1985 to \$2 million from the \$1 million-a-year level that had been in effect since 1980.

Collaborative work with faculty and students at Caltech and other universities is an important objective and is strongly encouraged, both for its own sake and as a source of fresh stimulation to exploratory investigations. It is a matter of satisfaction, therefore, that faculty collaborators were involved in 16 of the DDF tasks that were newly funded in 1985.

PRESIDENT'S FUND

The Caltech President's Fund (PF) provides a second, though smaller, source of discretionary funding. Under sponsorship of the President's Fund, 18 new tasks were begun in 1985. Funds are provided by Caltech and NASA on a matching basis. In 1984 NASA increased its commitment under the arrangement from \$350,000 to \$500,000 a year.

The special aim of the President's Fund, which is administered by Caltech, is to encourage and facilitate faculty and student participation in research activities of importance to JPL, at the same time affording JPL staff members opportunities for close collaborative contact with able research workers from the university community. The new tasks in 1985 involve, besides Caltech, the University of Southern California, the University of Illinois, Cornell University, two campuses of the University of California, and University College London.

NASA HONOR AWARDS

The NASA Honor Awards program gives special recognition to outstanding individual and team efforts. Twenty JPL individuals and seven groups won awards in 1985:

NASA Outstanding Leadership Medal

Duane F. Dipprey
Gael F. Squibb



*NASA Exceptional Scientific
Achievement Medal*

*Amitava Gupta
Joseph Maserjian
Zdenek Sekanina
Joe W. Waters*

*NASA Exceptional Engineering
Achievement Medal*

*Robert E. Freeland
William G. Melbourne
Robert Nathan*

*NASA Exceptional Service
Medal*

*Charles Beichman, Edward R. Caro,
Elmer L. Floyd, Terry W. Koerner,
Thomas H. May, Sylvia L. Miller,
Eni G. Njoku, Donald G. Rea,
Bruce T. Tsurutani, Gerald E. Voecks,
Ivan Dale Wells*

*NASA Group Achievement
Award*

*Goldstone 64-Meter Antenna
Repair Team*

Networks Consolidation Program Team

*Photographic Support Team for
FAA Aircraft-Controlled Impact
Demonstration*

*Pilot Ocean Data System
Development Team*

SERIES-X Project Development Team

*Shuttle Imaging Radar (SIR-B)
Development Team*

*NASA Office of Inspector General
at JPL*

**PATENTS AND TECHNOLOGY
UTILIZATION**

The Office of Patents and Technology Utilization evaluates, patents, and helps NASA provide the public with technical information on the inventions and technological innovations resulting from JPL work. In 1985, 201 inventions and innovations were reported to NASA and other sponsors of JPL.

The U.S. Patent Office issued 52 patents to Caltech and NASA for JPL inventions. The Office of Patents and Technology Utilization also helped NASA and Caltech identify potential licensees who had an interest in NASA- or Caltech-held patents, issued or pending.

The JPL Office of Patents and Technology Utilization provided information, in response to inquiries, for further information on subjects

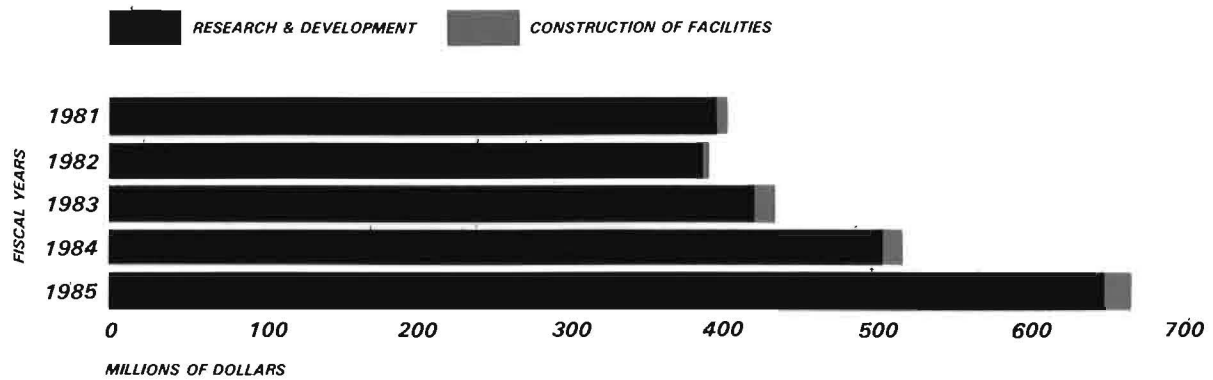
included in NASA Tech Briefs to 49,342 individuals and companies.

NASA made monetary awards to the following JPL employees and former employees in 1985:

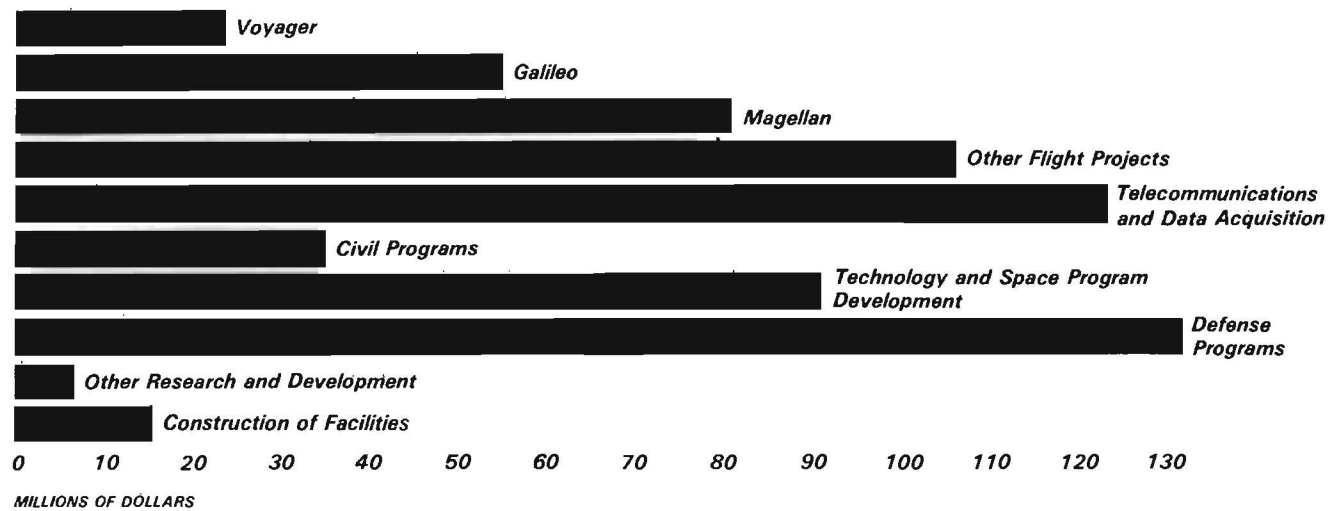
- ☆ *Combined technical contributions to planetary and biomedical image processing and scientific data analysis techniques by Dr. Robert Nathan, \$20,000.*
- ☆ *Electromagnetic Power Absorber by Richard Iwasaki, \$5,000.*
- ☆ *Paired, separately controlled, and coupled or uncoupled stripe geometry semiconductor lasers by Joseph Katz, Amnon Tariv, Shlomo Margalit, Elyahou Kapon, and Seiji Mukai, \$2,500.*
- ☆ *Sealed bipolar multicell battery by John J. Rowlette, \$1,000.*
- ☆ *Tech Brief: Minimum and nominal patent awards to 364 awardees, \$42,000.*



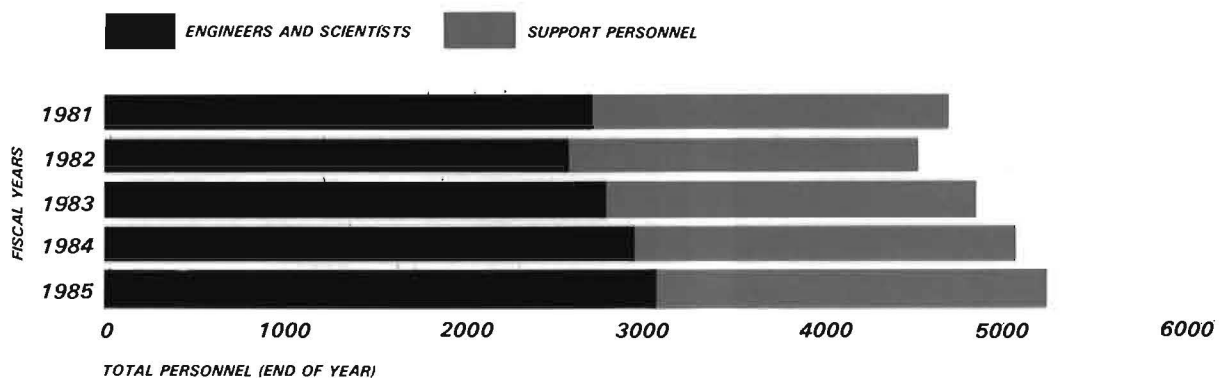
TOTAL COSTS



FISCAL 1985 COSTS



PERSONNEL



JET PROPULSION LABORATORY EXECUTIVE COUNCIL

Lew Allen

Director

Robert J. Parks

Deputy Director

Moustafa T. Chahine

Chief Scientist

Joseph P. Click

*Assistant Laboratory Director —
Administrative Divisions*

Frank Colella

Manager—Public Affairs Office

Fred H. Felberg

Associate Director—Institutional

Donald R. Fowler

General Counsel

Clarence R. Gates

*Assistant Laboratory Director—
Technical Divisions*

W. Gene Giberson

*Assistant Laboratory Director—
Flight Projects*

Jack N. James

*Assistant Laboratory Director—
Defense and Civil Programs*

Peter T. Lyman

*Assistant Laboratory Director—
Telecommunications and Data
Acquisition*

Donald G. Rea

*Assistant Laboratory Director—
Technology and Space Program
Development*

Geoffrey Robillard

*Assistant Laboratory Director—
Engineering and Review*

Harris M. Schurmeier

*Associate Director—Defense and
Civil Programs*

Walter K. Victor

*Assistant Laboratory Director—
Computing and Information Systems*

TRUSTEE COMMITTEE ON THE JET PROPULSION LABORATORY

Shirley M. Hufstedler

*Chairman, Trustee Committee
on JPL; Caltech Trustee;
Partner, Hufstedler, Miller,
Carlson & Beardsley*

R. Stanton Avery

*Chairman Emeritus,
California Institute of Technology;
Founder Chairman,
Avery International*

Harold Brown

*Caltech Trustee; Chairman, Foreign
Policy Institute, The Johns Hopkins
University, School of Advanced
International Studies*

Walter Burke

*Caltech Trustee; President, Sherman
Fairchild Foundation, Inc.*

Lee A. DuBridge

*President Emeritus,
California Institute of Technology*

Charles C. Gates

*Caltech Trustee; Chairman of the
Board and President,
The Gates Corporation*

James W. Glanville

*Caltech Trustee; General Partner,
Lazard Freres & Company*

Marvin L. Goldberger

*President, California Institute of
Technology*

Fred L. Hartley

*Caltech Trustee; Chairman and
Chief Executive Officer,
Unocal Corporation*

Ralph Landau

Caltech Trustee; Listowel Inc.

Robert S. McNamara

*Caltech Trustee; Former President,
The World Bank*

Ruben F. Mettler

*Chairman, Board of Trustees,
Caltech; Chairman and Chief
Executive Officer, TRW Inc.*

Gordon E. Moore

*Caltech Trustee; Chairman and Chief
Executive Officer, Intel Corporation*

Pamela B. Pesenti

Caltech Trustee

Simon Ramo

*Life Trustee, California Institute
of Technology; Director Emeritus,
TRW Inc.*

Stanley R. Rawn, Jr.

*Caltech Trustee; Chairman of the Board,
Adobe Resources Corporation*

Mary L. Scranton

Caltech Trustee

Roger B. Smith

*Caltech Trustee; Chairman,
Board of Directors, General
Motors Corporation*



National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California